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EFFECT OF EXPOSURE TO OXYGEN ON CHANGES IN MEATS AND VEGETABLES DURING STORAGE

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WHIRLPOOL CORPORATION
Systems Division
St. Joseph, Michigan

Contract No. DA 19-129-AMC-131 (N)

NOVEMBER 1965

U. S. Army Materiel Command
U. S. ARMY NATICK LABORATORIES
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Project Reference:
1K643303D548

November 1965

U. S. Army Material Command

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FOREWORD

Freeze dried foods are very susceptible to oxidative deterioration during storage. It is generally accepted in the industry that such products should be packaged with an inert gas such as nitrogen with two percent or less oxygen in the headspace gas. However, the two percent is an empirical limitation which may be tighter (and thus more expensive) than necessary. In addition, it has been suggested that the moisture level limitations in the products are tighter than necessary for satisfactory keeping qualities.

The work covered in this report, performed by the Whirlpool Corporation under Contract No. DA19-129-AMC-131(N), was designed to obtain acceptance data after storage on four typical products prepared at two moisture levels and packaged at three oxygen levels. Dr. Norman G. Roth was the Official Investigator.

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ABSTRACT

Reported are the procedures and results of a six-months storage stability study conducted with precooked beef, chicken, carrots and spinach which had been freeze-dried to 2 and 4% residual moisture level and stored under 2, 4, and 20% oxygen atmosphere at 100°F. Exposure to oxygen was the primary cause of product deterioration. The effect of residual moisture level and length of storage on quality attributes was product dependent.

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SUMMARY

The quality of precooked, freeze-dehydrated beef, chicken, carrots, and spinach deteriorates rapidly in adverse storage environments. The type and extent of deteriorative reaction are dependent to a greater or lesser degree on each of the study variables: residual moisture level, headspace oxygen concentration, and duration of storage at elevated temperature. The specific biochemical and biophysical properties of each food determine its ability to tolerate some variations in these environmental factors without serious impairment of quality attributes.

Exposure to oxygen appeared to be the most significant factor in degradation of products stored at elevated temperature. Since freeze-dried foods are extremely porous, rather large surface areas are exposed to whatever atmosphere surrounds them. Consequently, volume and composition of the container headspace atmosphere determine the extent of exposure of the product during storage. Container headspace used in this investigation varied from 70 to 90% of the total volume of the container. This substantial volume coupled with the large surface area of the dried food products provided an appreciable exposure of these products to even moderately low oxygen partial pressures during storage. Thus, oxidation could proceed at a rapid rate unhampered by penetration barriers and the total damaging effect would be nominal within the limits of available oxygen.

Another route for oxidative damage of freeze-dried products is exposure to air during the interval between removal of the product from the freeze-drier and sealing in the packaging container. Molecular oxygen is rapidly and tightly bound by these products and desorbed slowly, or perhaps not at all, during storage. This bound oxygen could account for an appreciable

amount of oxidative damage during the storage period. Further, during this investigation there were indications that the rate of oxidation of some components, when exposed to air, was sufficiently rapid to overshadow the effects of low oxygen concentrations in the storage atmosphere. However, the test conditions used for this study were such that the relative effects of pre-packaging air exposure and storage atmosphere could not be differentiated. Analysis of headspace atmosphere within a short time after completion of the packaging operation documents the use of pre-purified nitrogen in the packaging operation. However, in view of the foregoing, this determination may not indicate exposure of a product to air oxidation during the packaging operation. With this in mind, there are several areas in the packaging operation which might bear close scrutiny: the interval between termination of the dehydration cycle and completion of the packaging operation and a precise definition of conditions adequate to protect the product from oxygen and moisture during this interval. These conditions do not appear to be specified in product descriptions. A maximum interval of eight hours between release of the vacuum of the freeze-drier and completion of the packaging operation is indicated for chicken. The intervals are not specified for the other products.

Although deteriorative changes are apparent, packaging under a 2% oxygen atmosphere after limited exposure to atmospheric oxygen did not degrade the products to the point of terminating storage. These conditions afford adequate stability for six months at 100°F.

INTRODUCTION

The perfect preservation of foodstuffs requires control of the entire processing operation. Each phase of the processing operation from selection of raw product through conditions of final storage must be considered. There are innumerable variables within each phase of the processing operation which may affect product quality significantly.

Thus problems associated with the freeze-dehydration of foodstuffs may stem from a number of sources: variety or breed; cultural or nutritional factors; maturity at harvest or slaughter; method of harvest or slaughter; post-harvest or -slaughter handling; preliminary heating, cooling, freezing, or other treatments; dehydration cycle; manner of packaging; and storage temperature.

Each of the various steps in the processing operation can be of critical importance either in itself or by virtue of its effect on the other aspects of processing. Accordingly, quality attributes are subject to change during storage at rates dependent on the nature of the raw product, the methods of handling and processing, and storage environment.

It is the influence of the atter on food quality attributes which is of particular concern. Foods re complex biological systems and, therefore, are inherently unstable and sensitive to exposure to adverse storage environments.

Storage stability is an extremely acute problem in military supply. The end point of useful storage life must be determined under realistic conditions. In general, stability for a 6 month period at 100°F is required for military rations.

Deteriorative reactions, whether oxidative or non-oxidative, are accelerated by high temperature storage. Other than temperature, storage environment is a function of atmosphere or oxygen content of the headspace of the storage container and the residual moisture content or, more appropriately, the equilibrium relative humidity of the dehydrated product.

The effect of these environmental variables has been studied. However, neither optimum nor tolerance levels have as yet been determined. In particular, the variations in deteriorative processes and rates at low levels of oxygen concentration and moisture content have not been adequately investigated. Most investigations have concentrated on the storage characteristics of raw meats. The storage stability of pre-cooked, freeze-dehydrated product has received little attention. Therefore, this investigation was undertaken to identify the level of oxygen concentration in the headspace of the storage container which is associated with a significant change in quality and to determine whether moisture content contributes appreciably to this change in quality in four basic commodities: pre-cooked, freeze-dehydrated beef, chicken, carrots and spinach.

PROCEDURES

I. Procurement and Storage

As indicated, the raw material is the first limiting factor. Both plant and animal materials are biological and inherently variable. Thus the quality of the raw materials affects the quality of the freshly dehydrated product and may determine its storage life. Similarly, the physical and chemical changes in foodstuffs resulting from methods of harvest or slaughter or from handling or food preparation techniques affect the quality of both the freshly processed and stored dehydrated products.

Accordingly, a number of precautions were exercised in order to render validity to the experimental design in a study confined to a relatively small number of samples. The experiment was designed to control or standardize all variables except those under study. Each of the commodities was purchased fully prepared for freeze-dehydration according to the applicable military limited production and interim purchase descriptions. This measure assured compliance with commercial production practices. In addition, purchase orders specified a single product lot in order to minimize within-sample variations caused by raw material variables. Furthermore, each product was processed for freeze-dehydration in a single production lot in order to restrict variables in each phase of the preparation operation which might affect product quality significantly. The following Table details pertinent information for the vegetables.

Product	Purchase Description	Type	Style	Variety	Location of Field	Maturity: Planting Date	Maturity: Harvesting Date
Carrots	C-170-61 CS-5-1 (freezing)	II	B	Imperator	Luther Pruit Ranch Indio, California	10-10-63	4-6-64
Spinach	C-208-63			99 x 99	One mile South of Crow's Landing, California	9-16-63	11-26-63

The raw materials and preparation for poultry and beef products conformed to Class 1 product described in Interim Purchase Description CS-5-1 and to Type I, Style 1 product described in Limited Production Purchase Description C-190-62, respectively. All beef cuts were obtained from a single carcass. Liquid carbon dioxide freezing technique at -108°F was employed in the preparation of the precooked chicken. Reportedly this procedure does not affect product quality significantly. However, it is understood that the poultry processing industry is undertaking studies of the relationship of freezing technique to product quality.

Products were transported in the frozen state and stored prior to freeze-dehydration at -10°F. Portions of each product lot were randomly selected for the various drier loads.

II. Dehydration

All food products were freeze-dehydrated in a Repp Industries Model 11-40 Sublimator. Drying procedures used for beef conformed to Limited Production Purchase Description, C-190-62, Beef, cooked, sliced, dehydrated, dated 27 August 1962. Drying procedures used for chicken conformed to Interim Purchase Description CS-5-1 Chicken Pieces, precooked, dehydrated, dated 15 May 1961. Heat was applied to the dryer trays by direct platten contact. Drying procedures for carrots and spinach employed radiant heat and sublimation was carried out within the pressure range of 0.5 to 1.5 Torr. Platten and radiant panel temperatures were maintained below 149°F throughout the sublimation process.

Upon completion of drying, the chamber vacuum was broken with certified pre-purified nitrogen. Lids were automatically sealed onto trays containing control product lots before the drying chamber was opened. These trays were immediately transferred to a glove box flushed with certified prepurified nitrogen.

III. Packaging and Storage

Each drier load or moisture treatment lot of the test products was thoroughly mixed and randomly distributed among the storage containers. A standard amount of each product was weighed into No. 2½ (401 x 411) cans coated with tin plate. Product was fairly tightly packed into the cans without causing excessive damage to the physical integrity of the product. The following table indicates the weight of product used in this investigation.

Weight of Product Per Storage Container, Grams

Product	Weight
Beef	150
Chicken	175
Carrots	40
Spinach	30

After a one hour exposure to atmospheric oxygen, lids were sealed with a conventional can sealer and punctured for evacuation and flushing. The storage containers were randomly divided into groups for storage under the various headspace atmospheres.

The partial pressures of oxygen in the headspace of the containers were 11-15 mm Hg., 26-30 mm Hg., and approximately 150 mm Hg. For convenience, these packaging conditions are described as 2, 4, and 20 percent oxygen atmospheres throughout this report.

Samples stored under the highest headspace oxygen concentration were packaged in air. Certified oxygen-nitrogen mixtures provided the required storage atmospheres for products stored under lower partial pressures of oxygen.

Storage containers were evacuated and flushed repetitively to assure the specified initial storage atmospheres. Canning equipment produced a vacuum of less than 1 mm Hg. during evacuation. Final sealing was accomplished with solder.

Control or reference samples were packaged in a similar manner. However, these products were packaged without exposure to atmospheric oxygen in a glove box with an atmosphere of certified, prepurified nitrogen.

Test samples were stored at 100.4 $\pm$ 1.8^{o}F and control samples at -10^{o}F. Units were randomly selected for withdrawal from storage at monthly intervals.

IV. Chemical Analyses and Physical Tests

All analyses and measurements were performed in duplicate.

Chemical analyses were performed to establish the adequacy of processing in regard to degree of dehydration.

1. Fat Content

Representative samples from each drier load of dehydrated meats were analyzed for crude fat content using petroleum ether as the solvent according to the method of analysis of the Association of Official Agricultural Chemists. Mean values for these determinations are listed in Table I.

TABLE I

Fat Content, Percent

	Test Samples		Control Samples	
Product	Lot 1	Lot 2	Lot 3	Lot 4
Beef	15.93	26.96	17.40	10.55
Chicken	12.30	11.98	13.13	12.63

2. Residual Moisture Content

Representative portions of the product from each drier load were analyzed for residual moisture content. Residual moisture content was determined by both the Karl Fischer titration method and the appropriate oven technique specified by the Association of Official Agricultural Chemists. The Karl Fischer method was used as an immediate indication of the end point of the dehydration cycle. The accuracy of this method in estimating moisture content was then verified by the standard methods of analysis of the Association of Official Agricultural Chemists. Weighed samples of dehydrated meat were heated in an air drying oven at 212 - 215.6°F for 24 hours. Weighed samples of dehydrated vegetables were heated for 16 hours in vacuo at 158°F.

The average residual moisture content reported in Table II are based on values obtained using oven methods of analysis. The moisture contents of meat products were also calculated on a fat-free basis. For convenience, the lower residual moisture content is termed 2% and the higher 4% in the discussion, tables, and figures throughout this report.

TABLE II

Residual Moisture Content, Percent

Product	Test Samples						Control Samples	
	Lot 1 (2%)		Lot 2 (4%)		Lot 3 (2%)		Lot 4 (2%	
	Moisture	Fat Free Moisture	Moisture	Fat Free Moisture	Moisture	Fat Free Moisture	Moisture	F... Mo...
Beef	1.34	1.59	2.99	4.09	0.36	0.44	1.20	1
Chicken	1.47	1.68	3.42	3.89	0.39	0.45	0.42	0
Carrots	1.64		4.65		1.46		*	
Spinach	1.83		4.93		1.10		*	

* Only one lot of control product was processed.

3. Headspace Gas Analysis

Just prior to opening cans of stored products for sensory testing, the headspace gas in each can was analyzed for pressure, oxygen content and carbon dioxide content. Samples were taken and pressure were determined with a Beckman Headspace Sampler. Oxygen and carbon dioxide content of the headspace gas was determined by standard Orsat procedures.

4. Total Water Absorption

Ability of the dried products to absorb water was determined within 20 minutes of opening the drier and within 10 minutes of opening the cans of product prior to sensory evaluations. Mixed homogeneous 1 g. samples of product were selected and accurately weighed. Samples were transferred to glass storage dishes and immersed in an excess of water at 176 - 179.6°F for 10 minutes. Following immersion, samples were drained for 5 minutes and carefully reweighed. Total water absorption was determined from the gain in weight after immersion.

5. Water Binding Capacity

A variety of methods have been employed for determination of water binding capacity of food products. These include sedimentation, centrifugation, filtration and pressing. Most of these methods were developed for analysis of meats. There appears to be a paucity of information in the literature on determining water binding capacity of vegetables.

Pressing appears to be the method of choice of most authors. However, there is little if any agreement among them as to the best method. Data have been obtained from samples ranging from pieces to homogenates. Pressures applied range from 250 psig to over 10,000 psig; however, it is seldom clear whether these values refer to ram pressures on the press or to the actual pressure applied to the sample. Therefore, it is difficult to determine just what force was applied to obtain the results stated.

The press method was selected for determination of the water holding capacity of foods used on this project. A water expression die set was constructed of stainless steel. This device consisted of a 1.5 inch inside diameter sleeve into which two pistons or rams were placed one above the other. The top ram was solid metal with an "O" ring seal to prevent leakage. The bottom ram was also fitted with an "O" ring seal, but this ram was hollow and a 1/32 inch hole was bored through the center of the ram head. This hole allowed expression of water from the food sample. A heavy woven stainless steel screen was placed on top of the bottom ram and a die cut disc of #41h Whatman filter paper was placed on the wire screen. The screen and filter allowed free passage of water but prevented extrusion of the food sample through hole in the bottom ram.

Food product samples for determination of water holding capacity were prepared by immersion in 176 to 179.6°F water as described under procedure for determination of total water absorption. Drained samples were transferred to the water expression die prepared as described above, a second disc of Whatman #41h filter paper was placed on top of the sample and the top ram was lowered into the sleeve. The assembled die and sample were placed into a Wabash hydraulic press model 12-10 and the unbound water was expressed under pressure. Beef and chicken samples were subjected to a force of 6,100 pounds or a pressure of 3446 psi on the sample within the 1.5 inch diameter die. Vegetable samples were extruded through the die at this force; consequently, they were subjected to a force of 1,500 pounds or 847 psi on the sample within the 1.5 inch diameter die. Force was applied for one minute then released and the pressed samples were removed and weighed. The amount of unbound water was calculated as the difference between wet weight and pressed weight of the sample.

6. Headspace Volume

Headspace gas volume of the canned products was determined by two methods. During analysis of the headspace gas for oxygen and carbon dioxide content, headspace volume was calculated from observations of the can pressure prior to sampling, sample volume, can pressure after sampling and barometric pressure. Volume results obtained by this differential gas pressure method were verified by a liquid displacement method. This method involved displacement of headspace gas with a measured volume of ethyl alcohol. Results of both methods agreed very well. Results obtained were nearly identical for all cans of a given product. Headspace volumes for each product were as follows:

	Headspace Volume, Ml.	% Volume Of Storage Container
Beef	700	81.2
Chicken	600	69.6
Carrots	735	85.3
Spinach	776	90.0
Empty Container	862	

V. SENSORY EVALUATION

A. Facilities

Environment influences the precision of judgments. The detection of differences in food qualities requires conditions conducive to concentration. Samples were judged in a quiet area, free of interruptions and distractions. Distraction was further reduced by use of a comfortable, air conditioned area.

The use of individual booths in the test area avoided collaboration or subtle influence of facial expressions of the other panel members, assuring individual response.

Where color judgments were not required or where appearance might influence judgment of the other attributes, products were judged under lighting which masked any color differences. Conventional lighting was employed only for the evaluation of the color of the vegetables.

B. Method

A multiple sample test was selected in order to compare product qualities resulting from the various treatments to those of the control or reference sample. A scalar difference from control test was used to determine the extent and direction of difference. The rating form is shown in the Appendix.

Testing was limited to four coded samples and the identified control or reference sample. The identified control was re-introduced into each experiment or included as a coded sample in order to document the extent of bias and provide a uniform base for analysis of scores.

Presentation orders and coding were completely randomized among the four commodities.

C. Judges

Those individuals most capable of recognizing differences in quality attributes were selected as panelists for each of the four commodities. Selection procedures are detailed in the Appendix.

D. Sample Preparation

Any variation in preparation technique influences judgment significantly. For this reason, a standard method of preparation was employed for each product.

A weighed amount of each commodity was reconstituted in a specific volume of water at 176 to 179.6°F. Samples were prepared without any seasoning. The reconstitution period was held constant for each commodity. Table I details reconstitution specifications.

TABLE I

Product	Sample	Sample Wt., Gm.	Reconstitution Water, Oz.	Reconstitution Time, Minutes
Beef	Test	72.0	8	10
	Control	144.0	16	10
Chicken	Test	84.5	12	12
	Control	169.0	24	12
Carrots	Test	19.0	11	10
	Control	38.0	22	10
Spinach	Test	14.0	9	10
	Control	28.0	18	10

During the reconstitution period, samples were protected from heat loss. In addition, reconstitution vessels were set in insulating jackets for sample service.

Porcelain crucibles were selected as service vessels. Odorless and tasteless, these vessels did not impart foreign characteristics to the samples. Flavor characteristics of a hot food may be markedly different if foods are allowed to cool. Accordingly, samples were served in crucibles which had been heated to the specified reconstitution temperature. Preliminary trials indicated that a temperature of approximately 140°F prevailed during evaluation of flavor, texture, and juiciness.

Each crucible was filled to essentially the same level for service. During service of the beef samples, the various cuts were distributed among the sample vessels. Similarly, essentially the same amount of light and dark chicken meat were placed in each crucible. Individual slices of carrot varied considerably in extent of fading on exposure to oxygen; representative portions of the test samples were presented to each panelist. Spinach was the most homogenous test product and presented no service problems.

For service, crucibles were covered with heated watch glass covers. This measure facilitated aroma judgment by controlling diffusion of volatile components.

Using these procedures, samples were uniform as possible in all respects except those to be evaluated.

E. Schedule

To ascertain that the samples were essentially the same at zero-time, each drier load was evaluated at the termination of the processing cycle. Test samples were withdrawn from storage and evaluated at monthly intervals based on processing date.

VI. STATISTICAL ANALYSES

All data relating to sensory and rehydration characteristics of the samples stored at elevated temperature were tested for significance by analysis of variance according to the method outlined by Snedecor (1956). Values were tested at the .05 and .01 levels of probability.

The mathematical model assumed here is:

$$\text{Value}_{ijkl} = \mu + M_i + O_j + T_k + MO_{ij} + OT_{jk} + MOT_{ijk} + e_{ijkl}$$

Where μ is the true average value over the whole experiment,

M_i represents the true differential effect of the i^{th} level of moisture.

O_j represents the true differential effect of the j^{th} level of oxygen, etc.

For purposes of calculating the F-ratios, it was assumed that moisture, oxygen and storage time were all fixed factors.

Since no true error term was available from this experiment, it was assumed that the three-factor interaction would have very little, if any, effect, and that its mean square could be used as the error term.

Where analysis of variance indicated that the storage atmosphere was a significant factor, the Duncan multiple range test for differences between means was performed to identify the level of headspace oxygen concentration associated with change in quality during storage. Values were tested at the .01 and .005 levels of probability.

A 2-tail t-test was used to determine whether residual moisture content affected oxygen absorption during storage. Values were tested at the .05 and .01 and .001 levels of probability.

The linear and quadratic relationship of ratings of sensory qualities was tested statistically and usually proved valid in adequately presenting the data. The degree of certainty with which each regression line represents the correlation for each sample over the entire storage period was calculated. This correlation is tabulated for each sample in the description accompanying each graph.

BEEF AND DISCUSSION

I. BEEF

The reactions which can cause loss of quality during storage of freeze-dehydrated beef include browning reaction, oxidation by molecular oxygen, protein denaturation, enzyme reactions, and microbial spoilage.

Dehydration to low residual moisture levels precludes deterioration from microbial spoilage during storage. While enzymes are generally destroyed by preliminary heat treatment, residual enzymes have been isolated in precooked foods (Olcott, 1962). However enzymatic deterioration appears to be relatively unimportant in dehydrated products with low residual moisture contents. Accordingly, a combination of both cooking pretreatment and adequate dehydration should prevent enzymatic deterioration during storage.

Thus non-enzymatic chemical reactions are indicated as the primary causes of deterioration. While these reactions may be conveniently classified as oxidative and non-oxidative (Tappel, 1956), the reactions are complex and interdependent (Tappel, 1955).

By virtue of the porous structure, freeze-dried foods expose a large surface area. Products are therefore capable of reacting chemically with large amounts of oxygen. Based on an investigation of the mechanism of oxidative deterioration in raw, freeze-dried beef, oxidation of ether soluble lipids is a minor factor. This fraction is responsible for approximately 10% of the total oxygen absorbed. More importantly, the oxidation of non-ether soluble conjugated lipids such as phospholipids and lipoproteins can account for 42 to 57% of the absorbed oxygen. The oxidation of non-lipid components was also clearly implicated in this study of oxidative deterioration (Tappel, 1956). The investigation of Chipault, et al (1961), on the other hand, indicated that lipid oxidation predominates and that non-fat components of precooked, freeze dehydrated beef do not absorb significant amounts of oxygen.

This apparent discrepancy reflects differences in the state of the protein in raw and cooked beef. The ability of hemoglobin and myoglobin to combine reversibly with oxygen depends on the specific protein linkage with native globin. Accordingly, denaturation of the globin destroys the ability of these pigments to complex or react reversibly with large amounts of oxygen. Conversely, denaturation greatly increases the susceptibility of these pigments to true oxidation (Watts, 1954). Susceptible as these pigments are after denaturation, it appears that there is sufficient time lapse for this oxidation during subsequent phases of the processing cycle, i.e., prior to dehydration.

Reaction of oxygen with neutral lipids, particularly the unsaturated fatty acids, causes rancidity. Unsaturated, conjugated lipids oxidize much more rapidly and contribute stale, putrid odors and flavors. The final oxidation products of unsaturated fats are primarily carbonyl compounds.

The principal non-oxidative deteriorative mechanism is the Maillard or browning reaction (Regier and Tappel, 1956A). Free amino groups of proteins and amino acids react with carbonyl groups of naturally occurring reducing sugars, glucose, mannose, and fructose, and their esters and with the aldehydes and other carbonyl compounds which are formed by decomposition of labile hydroperoxides, the first stable reaction product of fat oxidation.

Since concentration of carbonyl compounds is one of the limiting factors in browning (Regier and Tappel, 1956B), concurrent unsaturated fat oxidation catalyzes browning through production of carbonyl compounds which are available for secondary browning reactions (Tappel, 1955). Thus oxidative deterioration is indirectly coupled with active carbonyl-amine reactions and can account for the relationship between oxygen absorption and general deterioration of freeze-dried beef.

In addition to concentration of carbonyl compounds, browning reaction is regulated by the presence of inhibitors as well as by pH, storage temperature, and moisture content (Regier and Tappel, 1956B). According to Salwin (1963), moisture in excess of the monolayer represents free water and promotes browning reaction.

Browning reaction is characterized by the development of colorless intermediate compounds which react reversibly. Further reaction of these compounds yields yellow or brown polymeric products. Characteristic color changes are accompanied by changes in flavor and aroma. These alterations are attributed to the reaction of carbonyl compounds with low molecular weight amines rather than with proteins. In the early stages browning reaction may improve palatability of precooked, freeze-dehydrated beef through the development of beef extract and roast flavors. However, in the later stages of storage, there is complete loss of acceptability brought about by scorched, bitter flavors (Olcott, 1962).

The proteins of cooked meats are considered "denatured". Therefore, subsequent changes resulting from storage might be considered relatively unimportant. However, dried meats do change in texture during storage at rates dependent on the temperature of storage and residual moisture content.

Browning reaction causes insolubility of protein through introduction of inter-protein bonds. However, other cross linking mechanisms may be as important as those associated with browning since toughening can occur without any evidence of browning reaction (Connell, 1962).

RESULTS

Oxygen Absorption

As indicated in Table I, the absorption of oxygen from the headspace of the storage container by precooked, freeze-dehydrated beef was essentially the same at the two residual moisture levels. At the 2 and 4% levels of initial oxygen concentration, all of the oxygen had been absorbed during the first month of storage. In these cases, oxygen uptake or oxidation was a function of available oxygen.

Unsaturated fat oxidation generally increases with decreasing moisture content (Tappel, 1956). However, according to Groschner, et al (1959), oxidative processes require moisture and are inhibited if residual moisture content approximates 1 to 2%. Consequently, the differences in absorption of oxygen by the dry material stored in 20% oxygen atmospheres were examined. Analysis confirmed that no difference existed in amounts of oxygen absorbed at the two moisture levels. There was an increase in the amount absorbed by the product until the supply of oxygen was exhausted. As indicated, the rate of absorption decreased with time.

The absorption of oxygen during storage in this study is in sharp contrast to the desorption of oxygen noted in a storage study of raw and precooked, freeze-dehydrated beef (Thompson, et al, 1962). The effect of various transfers of product in air in that study as opposed to exposure of product to atmospheric oxygen for a one hour period in this investigation cannot be judged. However, it appears that variation in other techniques could account for differences in the headspace oxygen concentration. There are two procedures which must be considered. The first of these is the release of vacuum in the freeze-drier with dry air rather than nitrogen in Thompson's study. Because of the porous structure of the product, the first gas to contact the surfaces is probably absorbed to the greatest extent. According to Olcott (1962), exposure to air or oxygen should be avoided since, after such exposure, absorbed oxygen is difficult to remove from the product. Data presented in the two headspace atmosphere studies by Thompson, et al (1962) indicate that absorbed oxygen is desorbed very slowly during storage. The second area of concern is failure to evacuate and flush the storage container repetitively prior to sealing and storage. However, as indicated above, if the vacuum of the freeze-drier is released with air, the rate of release of oxygen may negate the effectiveness of any flushing technique. Reportedly, some exposure to air can be tolerated if the vacuum of the freeze-drier is released with nitrogen.

To summarize these comments, it is generally agreed that releasing the vacuum of the freeze-drier with nitrogen and repetitive evacuation and nitrogen flushing of the container during sealing operations are required for stability. However, the relative importance of these procedures, particularly in regard to the extent of repetitive evacuation and nitrogen flushing during sealing operations and the effectiveness of such procedures under various conditions of operation, does not appear to be documented.

Carbon Dioxide Production

Carbon dioxide production during storage of beef in this investigation is shown in Table II. Carbon dioxide production by samples stored under the lower oxygen partial pressures was erratic. While there was irregularity i production by samples stored in 20% oxygen atmospheres, there was a trend toward increased production with increasing storage time. Substantially greater amounts of carbon dioxide were detected in the 20% oxygen headspace atmospheres of samples processed to the 4% residual moisture level. Sharp (1958), in detailing an investigation of browning reaction in freeze-dried precooked pork stored in nitrogen, also noted production of carbon dioxide

According to the review of browning reactions in model systems compiled by Hodge (1953), carbon dioxide may be produced during browning in a number of reactions. Known possible sources include:

1. The carboxyl group of the alpha amino acids.
2. The carboxyl groups of amines and amino acids other than alpha
3. The alpha carbon sugar radical in sugar-amine reactions that occur in the presence of oxygen via oxidative fission of Amoradi re-arrangement products.

Quality Attributes

All samples decreased in acceptability with increasing time of storage at elevated temperature. Acceptability ratings tend to parallel those for aroma and flavor. Changes in these characteristics during storage are shown in Figures 1 2, and 3.

Rancid odors and flavors were not perceived until the mid-point of the storage period. These characteristics were first detected in the 4% residual moisture samples stored under 20% oxygen atmosphere. An induction period during which there is minimal absorption of oxygen and little detectable change in product qualities is typical of autoxidative reactions involving neutral lipids. In contrast, characteristics of active carbonyl-amine browning were readily apparent. Both of these reactions proceeded more rapidly in samples stored in 20% oxygen atmospheres. Because of the variation in rates of these reactions and because the development of bouillon and roast qualities might tend to mask rancidity, browning reaction appeared to be the main deteriorative reaction during storage.

Ratings of texture and juiciness did not follow the same pattern. Although a downward trend is evident, the relationship between these attributes and storage variables cannot be defined with confidence (Figures 4 and 5). The wide variation in texture and juiciness found among different cuts from the same animal is well documented in the literature. Consequently, there was considerable variation among samples of beef from the same storage container and this variation was reflected in sensory ratings. During the study, written product descriptions were encouraged. The initial frequency of comments regarding within-sample variations was considered significant. Undoubtedly, within-sample variation made the panel less critical of changes in structural qualities. Dryness and toughness were much more serious problems than indicated. These findings emphasize the necessity of eliminating this variable in the design of storage studies.

Rehydration Characteristics

Inherent variability also obscures results of physical measurements of rehydration characteristics. Meaningful data can only be obtained by comparing the rehydration characteristics of adjacent samples of the same muscle. The percent of water absorbed during rehydration is shown in Table III. Table IV shows the percent of loosely bound water. Mean values of duplicate determinations were corrected for residual moisture content of the sample lot.

Statistical Analyses

Table V summarizes the statistical analyses of sensory judgments and rehydration measurements. The analyses of variance of sensory ratings of acceptability, aroma, flavor, texture, and juiciness are presented in Tables VI through X; those of rehydration measurements are shown in Tables XI and XII. Data for analyses of variance of sensory characteristics are derived from Tables XIII through XVII; tabled values represent the mean rating of the ten panelists.

It is apparent that the storage atmosphere and duration of storage were the major factors in degradation of precooked, freeze-dehydrated beef held at elevated storage temperature. The oxidative effect was not significant at the lowest level of initial oxygen concentration. If oxygen is virtually excluded, the lipids are relatively stable and formation of carbonyl compounds which can participate in browning reaction is restricted. However, naturally occurring carbohydrates support browning reactions. On these bases, active carbonyl-amine browning reaction is the most important deteriorative mechanism at very low levels of headspace oxygen concentration.

It is unfortunate that the experimental design did not permit evaluation of the net effect of this limited oxidation. While temperature rather than concentration of carbonyl compounds is undoubtedly the major factor in rate of browning, it is well to document this phenomenon for purchase specification purposes.

At these levels of residual moisture content, moisture was not a significant factor in quality except as it may relate to rate of browning reactions and to moderation of change in structural properties. Dehydration to a residual moisture content of 2 percent did not inhibit browning reaction appreciably over the storage period.

Objective measurements supported the sensory evaluations of texture and juiciness. Drying to the lower residual moisture content appeared to have affected rehydration. The 4% moisture samples rehydrated to a greater extent. This additional water was not tightly bound and was released under pressure.

Hamm and Deatherage (1960) investigated the effect of extent of dehydration on water holding capacity of raw freeze-dried beef. The degree of dehydration influenced the amount of tightly bound water adsorbed in mono-and multi-molecular layers by certain protein polar groups. Dehydration caused biochemical changes in muscle tissue through removal of water molecules localized between peptide chains and attached to protein polar groups. This resulting proximity of adjacent peptide chains caused new cross linkages. As the consequence of this tightening of the spatial structure, there was a decrease in water holding capacity.

Perhaps because of the difference in structure caused by cooking and the relative rate of browning, this effect was not noted during this investigation. The higher moisture content did afford some protection, however, to the degree of rehydration. Subjectively, this easily expressed or unbound water gave the impression of better structure, since dryness of samples was not as apparent as it was at the lower residual moisture level. However, as previously indicated these observations are subject to question because of randomization of cuts.

Moisture level may be responsible for the terminal appearance of rancidity in the 4% moisture sample stored under 4% oxygen atmosphere and for the earlier detection of rancidity in beef dried to the 4% residual moisture level and stored under 20% oxygen atmosphere.

The residual moisture level appeared to affect the rate of oxidation. While absorption of oxygen by product dried to the two residual moisture levels was essentially the same, it appears that the chemical use of oxygen by the two substrates varies. The oxidative reactions which occur cannot be considered as a single entity for control purposes.

Apparently, the higher moisture level facilitates hydrolysis of those lipids responsible for rancidity. The orientation of unsaturated fatty acids at an interface can have a profound effect on oxidative reactions. Watts (1954) investigated the effect of orientation on oxidation of fatty acids. The oxidation of oleic acid, the principal component in the ether extractable lipids of beef, is facilitated by orientation at polar hydroxyl groups.

Conversely, lower levels of moisture appear to accelerate the oxidation of conjugated lipids since variations in rates of these two oxidative reactions at the two moisture levels were compensatory. To the authors' knowledge, the effect of orientation on oxidation of non-ether extractable lipids has not been documented. However, these compounds could react in a manner similar to that indicated by Watts for the more highly unsaturated ether soluble fatty acids. Although the rate of oxidation of the more highly unsaturated fatty acids is more rapid with increasing degree of unsaturation under a given condition, the oxidation of highly unsaturated fatty acids as linoleic and linolenic is retarded by orientation at polar hydroxyl groups.

These observations should be documented by physical and chemical investigation to define the relationship between extent of dehydration and the site of bound water and to determine the relationship between the residual moisture content of precooked freeze-dried foods and the type and rate of deteriorative reaction under various conditions of processing and storage.

Terminal Characteristics

Table XVIII describes product characteristics at the termination of the storage period. Typical amine odor and colors are apparent in the dehydrated state. Both of these characteristics intensify with rehydration. As indicated, only the products stored under 2% initial oxygen atmosphere can be considered acceptable. Yet these products exhibit gross defects, particularly in structural characteristics. Stored under apparently optimum conditions, low storage temperature and inert gas atmosphere, there was no detectable change in the 2% moisture control samples during storage.

RECOMMENDATIONS

It is essential that precooked, freeze dehydrated beef be handled and stored with little or no exposure to atmospheric oxygen. These results emphasize the merit of retaining and perhaps reinforcing provisions of procurement specifications which deal with exposure to oxygen. Product dried to the lower residual moisture level can tolerate somewhat greater amounts of oxygen without exhibiting the same extent of browning reaction or rancidity.

Moisture level appeared to exert a significant effect on structural characteristics. At these low levels of moisture, processing time and product throughout are important economic factors. If the reported variation in moisture content among samples from commercial drier loads can be adequately controlled 4% residual moisture content could be specified. As previously noted, recommendations relative to the effect of moisture on structural characteristics are subject to qualification. However, as indicated by variations in the development of rancidity, such a specification would necessitate absolute assurance of handling procedures in respect to exposure to oxygen. Accordingly, any specification for residual moisture level is necessarily compromised by individual processing procedures.

TABLE I

ABSORPTION OF HEADSPACE OXYGEN, ML. PER GRAM

Residual Moisture, Percent	Initial Storage Atmosphere % Oxygen	Months of Storage 1	2	3	4	5	6
2	2	0.11	0.11	0.11	0.11	0.11	0.11
	4	0.22	0.22	0.22	0.22	0.22	0.22
	20	0.57	0.81	1.04	1.29	1.29	1.29
4	2	0.12	0.12	0.12	0.12	0.12	0.12
	4	0.23	0.23	0.23	0.23	0.23	0.23
	20	0.60	0.92	1.11	1.23	1.28	1.31
Control	0	0	0	0	0	0	0

TABLE II

CARBON DIOXIDE IN HEADSPACE OF STORAGE CONTAINER, ML. PER GRAM

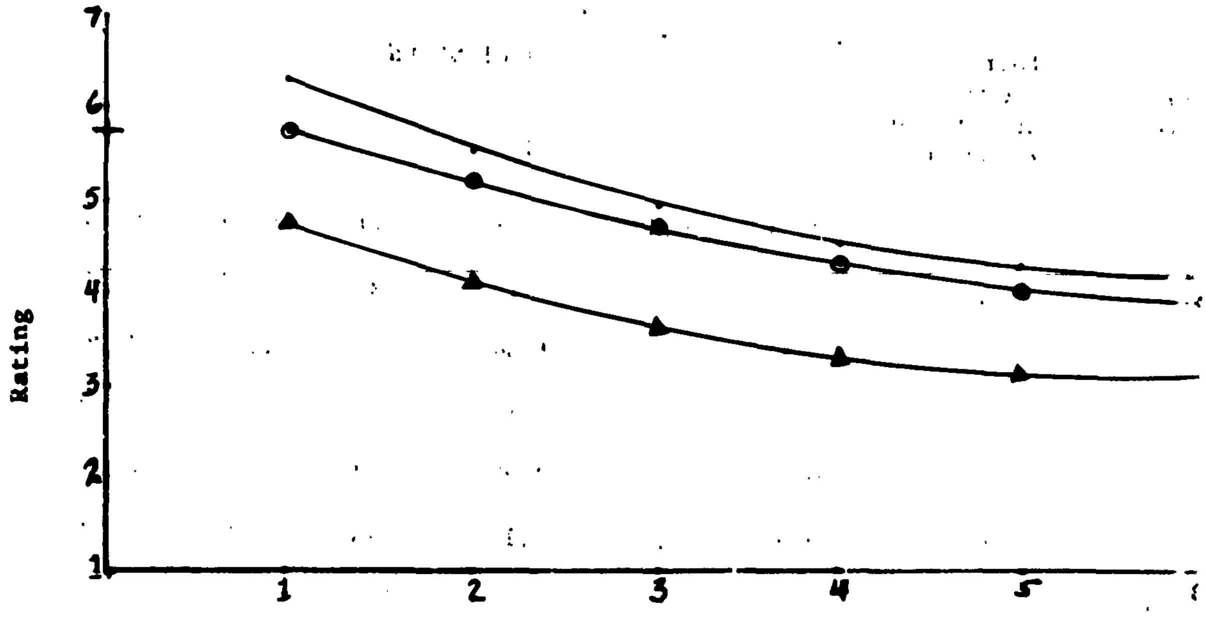
Residual Moisture, Percent	Initial Storage Atmosphere, % Oxygen	Months of Storage 1	2	3	4	5	6
2	2	0	0	0	.068	0	0
	4	0	0	0	.027	0	0
	20	0	0.061	0.068	0	0.074	.088
4	2	0	0	0	0	0.027	0
	4	0	0	0.027	0	0.089	0
	20	0.062	0.137	0.116	0.144	0.199	0.157
Control	0	0	0	0	0	0	0

Figure 1

BEEF ACCEPTABILITY

A. 2% Moisture Samples

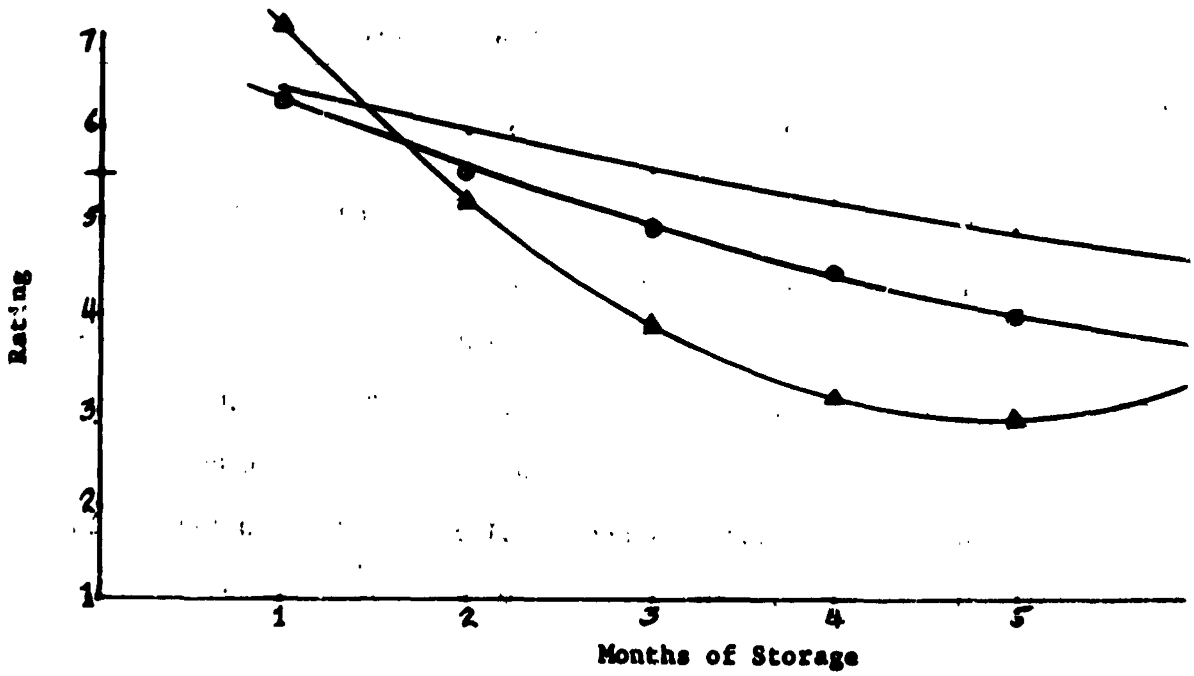
Initial Storage Atmosphere, % Oxygen:



Correlation/Initial Storage Atmosphere - 2%: .85; 4%: .92; 20%: .72

B. 4% Moisture Samples

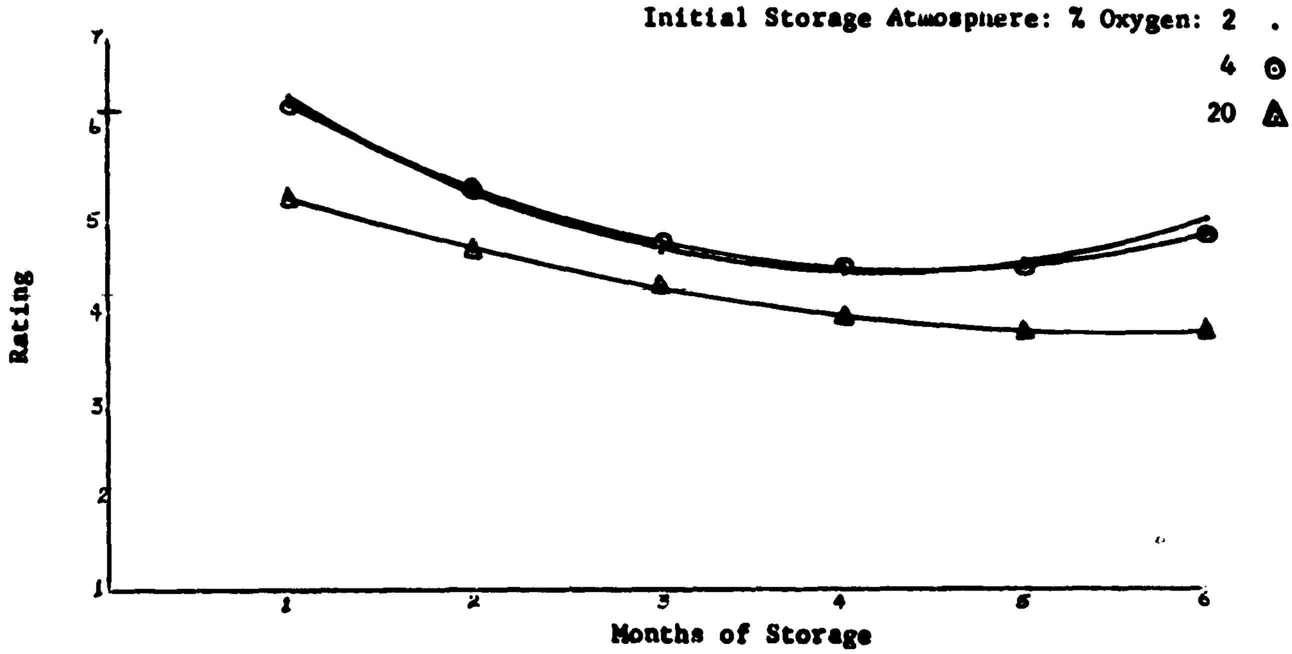
Initial Storage Atmosphere, % Oxygen:



Correlation/Initial Storage Atmosphere - 2%: .83; 4%: .62; 20%: .80

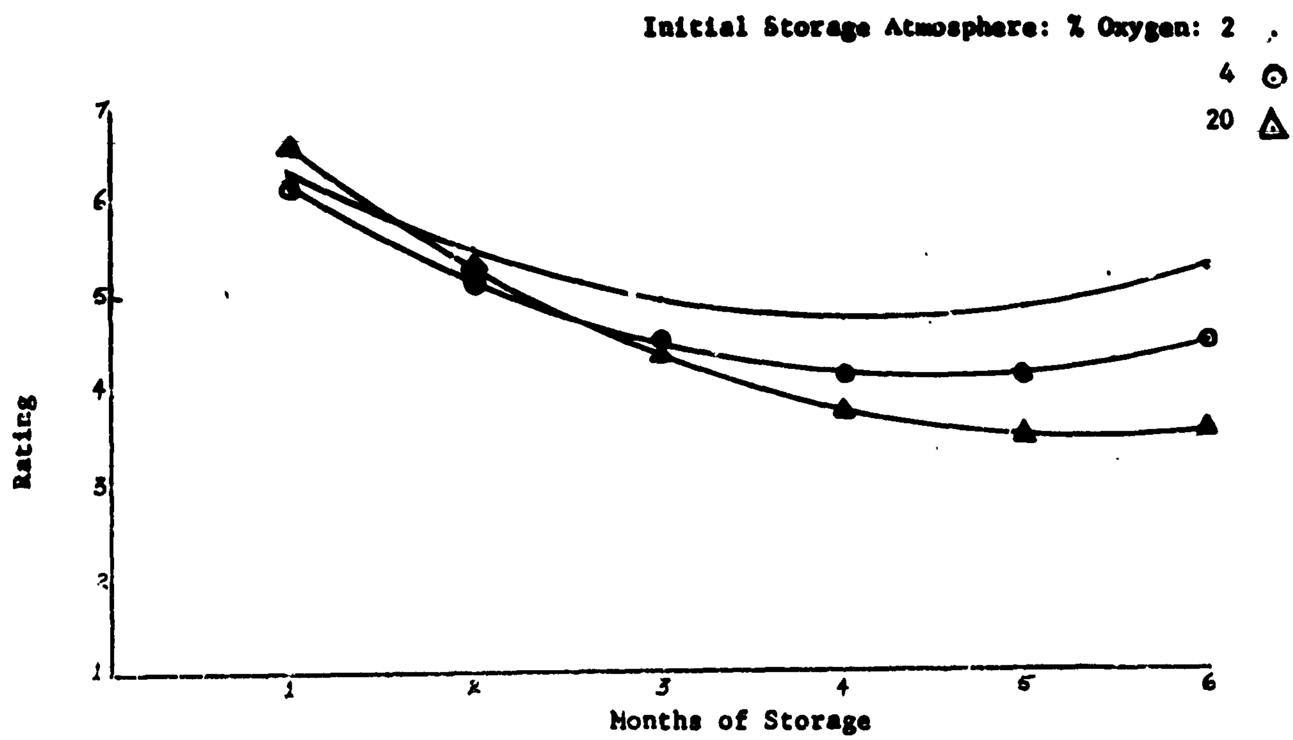
BEEF AROMA

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2: .70; 4: .94; 20: .49

B. 4% Moisture Samples

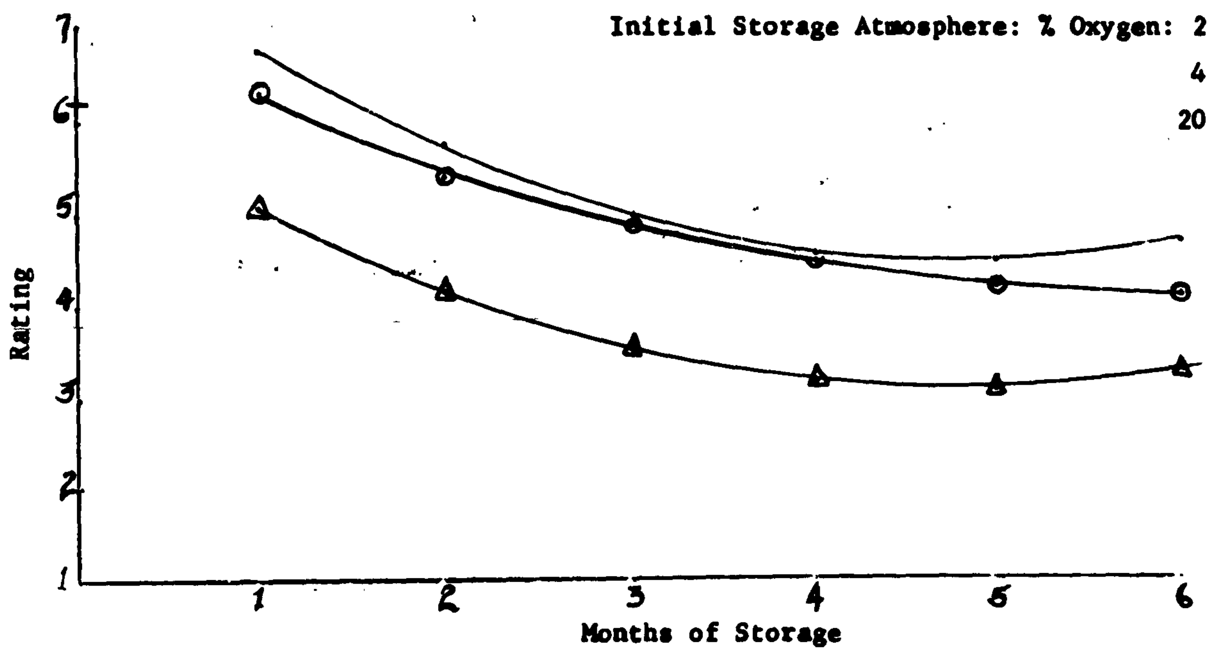


Correlation/Initial Storage Atmosphere - 2: .74; 4: .71; 20: .76

Figure 3

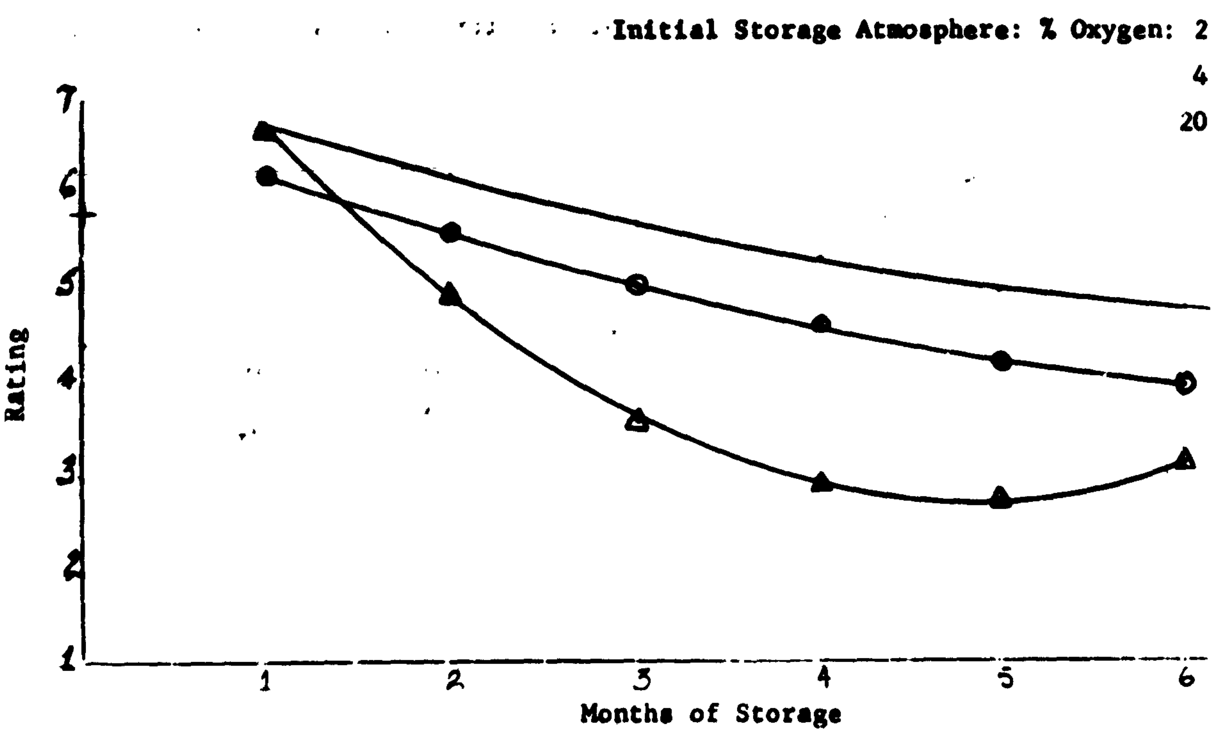
BEEF FLAVOR

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2: .80; 4: .91; 20: .85

B. 4% Moisture Samples

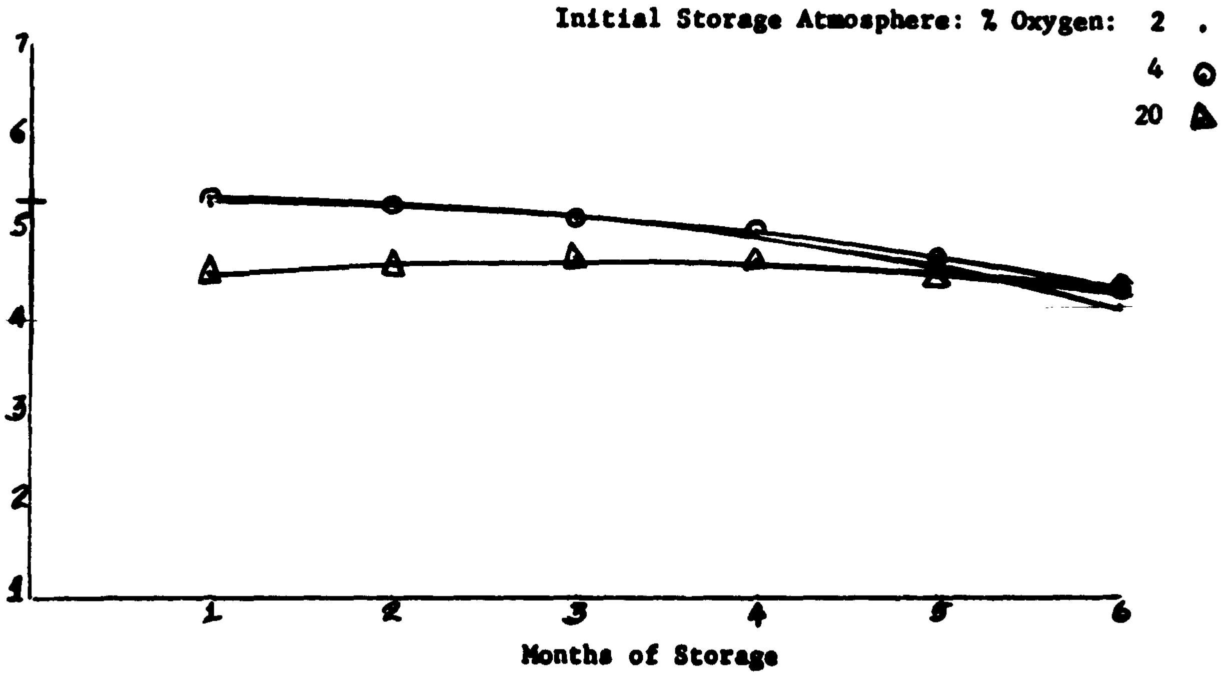


Correlation/Initial Storage Atmosphere - 2: .94, 4: .64; 20: .77

Figure 4

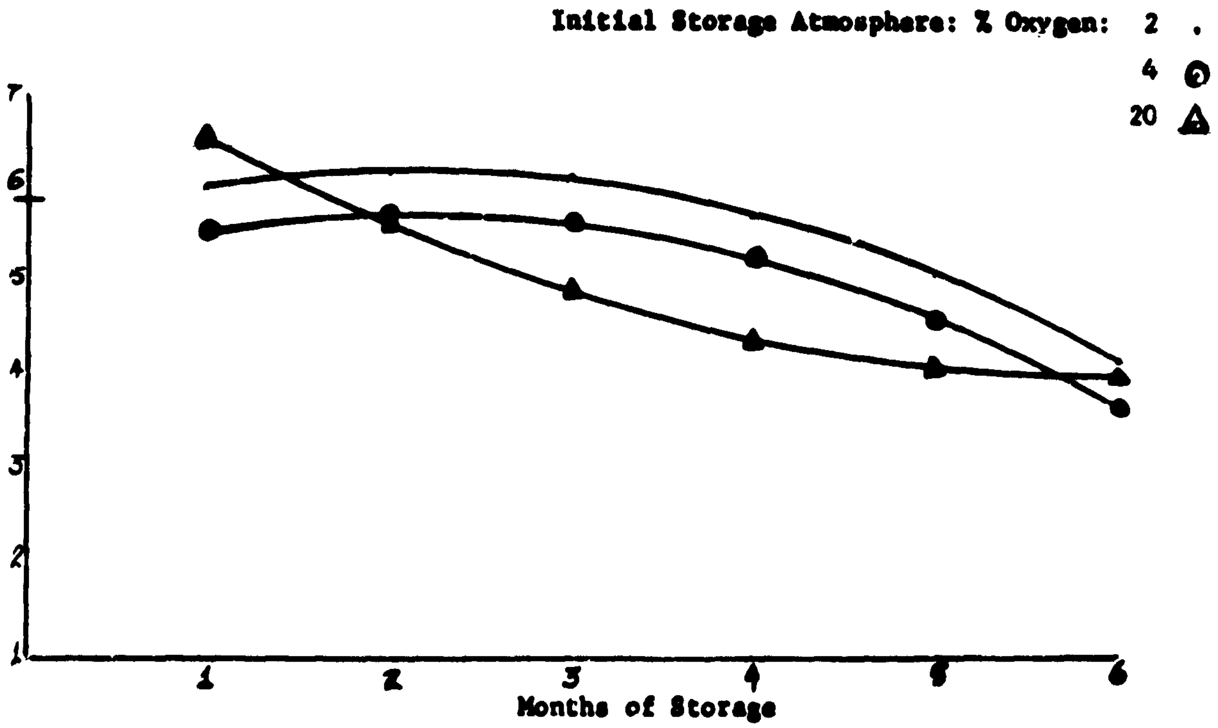
BEEF TEXTURE

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2: .89; 4: .89; 20. .06

B. 4% Moisture Samples



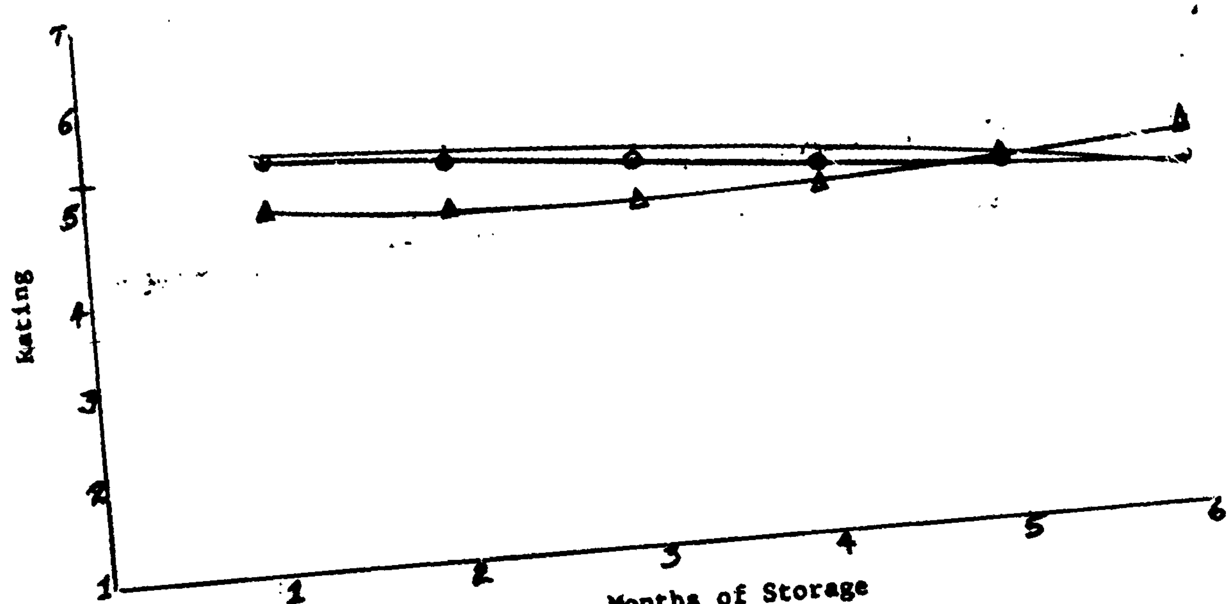
Correlation/Initial Storage Atmosphere - 2: .90; 4: .90; 20: .70

Figure 5

BEEF JUICINESS

A. 2% Moisture Samples

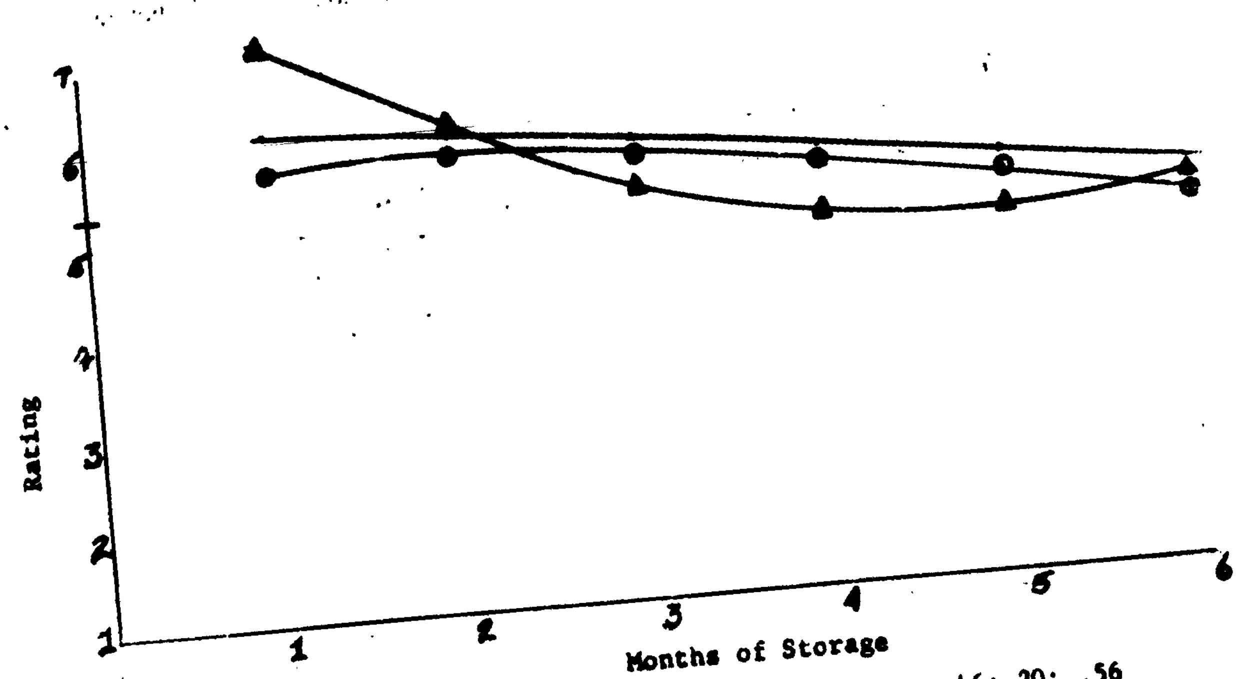
Initial Storage Atmosphere: % Oxygen:



Correlation/Initial Storage Atmosphere - 2: .65; 4: .89; 20: .17

B. 4% Moisture Samples

Initial Storage Atmosphere: % Oxygen:



Correlation/Initial S.orage Atmosphere - 2: .66; 4: .46; 20: .56

TABLE III

WATER ABSORBED DURING RECONSTITUTION,

PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Residual Moisture, Percent	Initial Headspace Oxygen Percent	Months of Storage					
		1	2	3	4	5	6
2	2	133	137	113	127	120	113
	4	120	129	125	131	122	128
	20	125	132	114	127	111	128
4	2	142	124	137	144	126	126
	4	131	125	140	132	124	127
	20	125	122	128	126	131	125

TABLE IV

UNBOUND WATER,

PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage					
		1	2	3	4	5	6
2	2	63	64	52	49	52	45
	4	50	53	60	56	42	49
	20	45	64	46	59	47	55
4	2	62	55	60	73	57	59
	4	57	54	58	66	[illegible]	58
	20	59	56	58	58	57	57

TABLE V

SUMMARY OF STATISTICAL ANALYSES

Test	Source of Variation	Sensory Judgments					Rehydration Measurements	
Analysis of Variance		Acceptability	Aroma	Flavor	Texture	Juiciness	Total Water Absorbed	Unbound Water
	Moisture, M				*	**	*	*
	Oxygen, O	**	*	**				
	Storage Time, T	**	**	**	**	**		
	MO							
	MT	*	*	*		*	*	
	OT							
Multiple Range	Initial Headspace	***	**	***				
	Oxygen, Percent	2/20	2/20	264/20				
		**						
		264/20						

* p = .05

TABLE VI

ANALYSIS OF VARIANCE: BEEF ACCEPTABILITY

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	1.43161	1.43161	4.86
Oxygen, O	2	9.17947	4.58974	15.59 **
Storage Time, T	5	25.65131	5.13026	17.42 **
MO	2	.31886	.15943	.54
MT	5	5.93265	1.18653	4.03 *
OT	10	2.02265	.20226	.69
MOT (Error)	10	2.94492	.29449	
TOTAL	35	47.48147		

TABLE VII

ANALYSIS OF VARIANCE: BEEF AROMA

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.03330	.03330	.13
Oxygen, O	2	3.57875	1.78937	6.76 *
Storage Time, T	5	17.30312	3.46062	13.07 **
MO	2	.46321	.23161	.87
MT	5	4.53217	.90643	3.42 *
OT	10	1.51892	.15189	.57
MOT (Error)	10	2.64836	.26484	
TOTAL	35	30.07783		

TABLE VIII

ANALYSIS OF VARIANCE: BEEF FLAVOR

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.55007	.55007	2.28
Oxygen, O	2	14.67056	7.33528	30.40 *
Storage Time, T	5	26.44951	5.28990	21.92 *
MO	2	.20872	.10436	.43
MT	5	4.77472	.95494	3.95 *
OT	10	2.20247	.22025	.91
MOT (Error)	10	2.41314	.24131	
Total	35	51.26919		

TABLE IX

ANALYSIS OF VARIANCE: BEEF TEXTURE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	1.27502	1.27502	5.38 *
Oxygen, O	2	1.32488	.66244	2.79
Storage Time, T	5	9.66009	1.93201	8.15 **
MO	2	.41979	.20990	.89
MT	5	3.65800	.73160	3.09
OT	10	1.26439	.12644	.53
MOT (Error)	10	2.37130	.23713	
Total	35	19.97347		

TABLE X

ANALYSIS OF VARIANCE: BEEF JUICINESS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	3.09174	3.09174	17.97 **
Oxygen, O	2	.30334	.15167	.88
Storage Time, T	5	5.37451	1.07490	6.25 **
MO	2	.16167	.08084	.47
MT	5	3.04118	.60823	3.54 *
OT	10	1.43303	.14330	.83
MOT (Error)	10	1.72036	.17204	
TOTAL	35	15.12583		

TABLE XI

ANALYSIS OF VARIANCE: WATER ABSORBED DURING RECONSTITUTION,

PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.02778	.02778	9.99 *
Oxygen, O	2	.01102	.00551	1.98
Storage Time, T	5	.03172	.00634	2.28
MO	2	.00702	.00351	1.26
MT	5	.05709	.01142	4.11 *
OT	10	.04055	.00406	1.46
MOT (Error)	10	.02781	.00278	
TOTAL	35	.20299		

TABLE XII

ANALYSIS OF VARIANCE: UNBOUND WATER,

PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.02890	.02890	8.70 *
Oxygen, O	2	.00695	.00348	1.05
Storage Time, T	5	.03163	.00633	1.91
MO	2	.00065	.00033	.10
MT	5	.02407	.00481	1.45
OT	10	.02722	.00272	.82
MOT (Error)	10	.03318	.00332	
Total	35	.15260		

TABLE XIII

BEEF ACCEPTABILITY, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
	2	6.150	5.700	5.200	4.625	3.650	4.500
2	4	5.700	5.250	4.875	4.450	3.725	4.100
	20	4.450	4.700	3.475	3.425	2.650	3.425
	2	6.500	5.750	5.900	4.800	5.250	4.425
4	4	6.700	4.400	6.000	4.025	4.277	3.550
	20	7.800	3.900	4.275	3.100	3.777	2.800

TABLE XIV

BEEF AROMA, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage					
		1	2	3	4	5	6
2	2	6.250	5.375	4.950	4.700	3.650	5.450
	4	6.100	5.575	4.750	4.450	4.250	4.950
	20	5.200	4.975	3.500	4.850	3.250	3.9[illegible]
4	2	6.300	5.500	5.150	4.200	5.330	5.100
	4	6.250	4.650	5.300	3.600	4.220	4.500
	20	6.950	4.450	5.100	3.150	4.170	3.300

TABLE XV

BEEF FLAVOR, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage					
		1	2	3	4	5	6
2	2	6.650	5.675	4.950	5.050	3.650	4.950
	4	6.050	5.425	4.700	4.800	3.850	4.200
	20	4.900	4.525	3.000	3.450	2.950	3.250
4	2	6.800	5.950	5.800	5.050	5.170	4.600
	4	6.600	4.450	5.800	4.350	4.330	3.750
	20	7.400	3.450	4.025	2.850	3.[illegible]00	2.600

TABLE XVI

BEEF TEXTURE, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen Percent	Months of Storage 1	2	3	4	5	6
2	2	5.150	5.400	5.250	4.650	4.600	4.200
	4	5.200	5.350	5.200	4.950	4.450	4.450
	20	4.250	4.800	5.300	4.000	4.350	4.600
4	2	6.100	6.000	6.300	5.350	5.390	4.000
	4	5.800	5.250	5.700	5.350	4.720	3.500
	20	7.050	4.650	4.875	5.150	3.940	3.800

TABLE XVII

BEEF JUICINESS, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	5.450	5.650	5.000	5.450	4.650	4.700
	4	5.500	5.300	5.000	5.150	4.850	4.700
	20	4.800	4.900	5.000	4.750	4.450	5.300
4	2	6.450	5.600	6.000	5.950	5.330	5.200
	4	6.200	5.050	5.900	5.850	5.280	4.700
	20	7.850	4.650	5.950	5.350	4.940	4.900

TABLE XVIII

PRODUCT DESCRIPTION,
TERMINATION OF STORAGE

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Dehydrated: Aroma	Dehydrated: Appearance	Rehydrated: Aroma	Rehydrated: Appearance	Rehydrated: Flavor	Rehydrated: Texture	Rehydrated: Juiciness
2	2	Amine	Yellow Cast	Mild Roast	Yellow Cast	Mild Roast	Tough	Dry
	4	Amine, Roast	Yellow Cast	Moderate Roast	Yellow Cast	Strong Roast	Tough	Dry
	20	Rancid	Brown	Rancid, Scorched	Brown	Rancid, Oxidized, Roast	Tough	Dry
4	2	Amine	Yellow Cast	Mild Roast	Yellow Cast	Mild Roast	Tough	Moderately Dry
	4	Amine, Roast, Rancid	Yellow Cast	Moderately Strong Roast	Yellow Cast	Strong Roast, Rancid	Tough	Moderately Dry
	20	Rancid	Brown	Rancid, Scorched	Brown	Rancid, Oxidized, Roast	Tough	Dry
2*	0	Odorless	Tan, Yellow Cast	Boiled Beef	Tan, No Yellow Cast	Boiled Beef	Moderately Tender	Fairly Juicy

* Storage Temperature: -10°F

II. CHICKEN

According to Harper, et al (1957), the mechanisms of storage deterioration of freeze-dried chicken are probably the same as those of beef.

Differences in the characteristics or reactions are attributable to species variation in such factors as type and degree of unsaturation of fat, content of globin and specific amino acids, and relative pigmentation.

Seltzer (1961), reviewing processing and storage criteria for freeze-dehydrated chicken, stated that freeze-dehydrated chicken deteriorated quite rapidly when exposed to air and stored at elevated temperatures. Furthermore, the induction period for autoxidation of free fat may be completed during processing, resulting in early development of rancidity during storage.

The mechanism of oxidative deterioration of freeze-dehydrated chicken was studied by Chipault, et al (1961). As in their study of precooked, freeze-dehydrated beef, these investigators observed that lipid oxidation can account for virtually all of the oxygen absorbed. Fat free tissue oxidized quite slowly. While residual lipids in the samples could account for this oxidation, the possibility of oxidation of protein, destroying labile amino acids, was also considered. Here again, the initial rapid rate of oxidation of the whole tissue suggested that the oxygen absorbed was used primarily to oxidize the non-ether extractable lipids and that decrease in rate of reaction was attributable to exhaustion of tissue supply of these unstable fatty acids. An induction period was typical of oxidation of ether extractable lipids. Oxidation of the bound lipids did not appear to have a prooxygenic effect on ether extractable lipids. Thus the relative participation of these two reactions in degradation of product in a closed vessel is a function of available oxygen and bound lipid content.

If moisture content exceeds 3%, carbonyl-amine browning occurs rapidly in chicken; other storage variables necessary for this reaction were not specified in the review (Seltzer, 1961).

Dryness and toughness are the most serious deficiencies associated with freeze-dehydration of chicken and storage under mild conditions. (Tappel, et al, 1957 and Seltzer, 1961).

RESULTS

Oxygen Absorption

The absorption of headspace oxygen by freeze-dehydrated chicken is shown in Table I. At the termination of the first month of storage, the available oxygen had been absorbed by samples stored under low oxygen pressures and all or essentially all of the available oxygen had been absorbed by the samples stored in the 20% oxygen atmospheres. The minor variation in amount of oxygen absorbed by samples stored in 20% oxygen atmospheres was not statistically significant.

This rapid absorption was also demonstrated in the study of oxidative mechanisms conducted by Chipault, et al (1961) and is considered characteristic of this tissue. It has long been known that the neutral fats of chicken are more easily oxidized than those of beef. Species differences are attributed primarily to fatty acid composition. The susceptibility of fat to oxidation depends on degree of unsaturation. For example, according to Watts (1954), linoleic acid may comprise 1 to 2% of the total triglycerides of beef and 8 to 31% of those of poultry.

Carbon Dioxide Production

Table II shows the production of carbon dioxide during storage. Variation in the amount of carbon dioxide produced by samples processed to the two residual moisture levels and stored under 20% oxygen atmospheres is noteworthy. The reason for this extreme variation is not apparent. However carbon dioxide production could be related to acceleration of reactions at the higher residual moisture level, i.e., browning reaction with concurrent hydrolysis of certain free fats.

Rehydration Measurements

Measurement of the amounts of water absorbed during reconstitution and easily expressed under pressure are shown in Tables III and IV. Data indicate inherent variability in raw product and the difficulty in conducting an objective analysis of these characteristics on samples which might vary widely in rehydration characteristics. It should be noted that, either in the dehydrated or rehydrated state, it was quite difficult to distinguish the breast from the thigh meat and that the majority of the cubes appeared to represent both of these tissues.

Hamm (1960), reviewing the biochemistry of meat hydration, indicated that hydration may be species related. There were indications that water holding capacity decreased in the following order: pork, beef, chicken. Apparently the fibrillar protein content is essentially the same among species but the content of globular protein is species dependent. Meats with the greater content of globular protein appear to have greater water binding capacity. Because of variation in fat content, rehydration measurements of the two meat products in this study are not directly comparable.

Quality Attributes

Figures 1, 2 and 3 show the changes in quality attributes of acceptability, aroma, and flavor during the storage period. A very close correlation between deteriorative changes in these qualities is apparent.

Changes in structural characteristics during storage shown in Figures 4 and 5 appear to be slight and irregular. Again, deterioration in structural qualities during storage was much more serious than indicated by the relative rating of samples. Biological variability undoubtedly influenced the scoring pattern. However, it is more probable that presentation of compressed blocks of samples generally composed of both light and dark meat confounded the evaluation of these attributes and made the panelists reluctant to document changes.

Statistical Analyses

The summary of statistical analyses is presented in Table V. Analyses of variance of sensory characteristics and rehydration measurements are shown in Tables VI through XII. Tables XIII through XVII show the average ratings of sensory qualities by the panelists through the study.

At this storage temperature, the oxygen content of the headspace was the most important storage variable. As indicated, only those samples stored under the lowest oxygen pressure failed to exhibit significant change attributable to oxidation during storage. Oxidation of non-ether soluble lipids appeared to be the primary deteriorative reaction.

According to Tappel, et al (1957) precooked chicken, freeze-dried to a residual moisture content of 2% and stored in a nitrogen atmosphere at 130°F, exhibited pronounced browning at the termination of the four month storage period. Product stored under identical conditions at 100°F apparently did not exhibit this characteristic and was reported to have good storage stability at 100°F for six months. Although some variation in flavor was indicated, no color change was observed between the stored sample and freshly dehydrated product. In the absence of oxygen and at this low residual moisture level, browning reaction in chicken appeared to be temperature correlated.

Similarly, browning reaction did not appear to be a primary reaction in the study of storage stability of precooked, freeze-dehydrated chicken stored under various oxygen atmospheres. However, since carbonyl compounds are products of fat oxidation and since fat oxidation leading to rancidity is known to have occurred, the reason for failure to exhibit typical characteristics of browning reaction is obscure. Accordingly, there are several observations which should be made at this point.

The characteristics observed correspond quite closely with those reported by Rolfe and Monro in a study of precooked minced dehydrated pork stored under various conditions (Sharp and Rolfe, 1958). The comparison appears apt in view of the preponderance of highly unsaturated fatty acids in both substrates. Rolfe and Monro observed the development of mealy attributes and yellow to yellow-orange color in meat adjacent to oxygen, while the remainder of the compressed block exhibited characteristics typical of non-oxidative browning reaction. These atypical characteristics also developed when loose packed granules of dehydrated meat treated with antioxidants were stored in air. The authors concluded that normal non-oxidative browning reaction which gives rise to meat extract, roast flavors and to brown discoloration was blocked at some stage when oxygen was present.

The development of unpleasant odors described as stale and putrid was also noted during the study of oxidative deterioration of chicken (Chipault, et al, 1961). Data obtained in a subsequent phase of that investigation indicated that bound lipid oxidation does not involve chain propagation and as a consequence, conventional antioxidants which inhibit chain reactions would be ineffective in preventing deterioration caused by oxidation of bound lipids.

Were it not for the similarity in characteristics and for the known fat oxidation, lack of browning might be related to storage temperature, substrate or poultry pretreatment, such as an aging procedure, which would retard glycolysis and limit the supply of any naturally occurring reducing sugars. That is, no brown discoloration could be expected if there were only a trace of reducing sugars present.

The dangers in generalizing from the observations made during this study of beef and that study of pork, i.e., from one product to another, are recognized. Neither this study nor that of Rolfe and Monro were substantiated by adequate chemical and physical tests. However, these atypical characteristics may be just other manifestations of browning reaction rather than inhibition of browning reaction by oxygen.

Since the volatile aldehydes of fats are known to vary in characteristics, there is no reason to expect that any given set of characteristics may be regarded as typical of browning reactions which occur under a wide variety of conditions.

Pippen, et al (1958) investigated the volatile carbonyls of raw chicken under oxidative conditions. However, the specific carbonyl compounds isolated were not related to product characteristics. The precise relationship between sensory qualities and type of carbonyl compound and possible route of browning merits investigation.

As indicated by Hodge (1953), the many different reactants and relations which are known to occur during browning in model systems necessitate analysis of the browning complex by identification of individual reactants and reactions in both model and natural food systems. Under a given set of conditions, the operative routes of browning and the extent to which one reaction affects another in a given food must be determined.

From the thorough review and organization of available literature (Hodge, 1953) several salient points deserve consideration:

1. The monomeric compound isolated from acidic glucose-glycine condensation product of browning reaction is nearly colorless but produces color on heating in water. This condensation product is more stable on standing in air than normal N-substituted glycosylamines.
2. Autoisomerization is a general characteristic of aldosylamines since most of them show decomposition to some extent on storage. However, if the beta hydroxyl is substituted, the Amoradi rearrangement and, therefore, browning which might otherwise have occurred is blocked. The beta hydroxyl is essential for the occurrence of a significant degree of browning.
3. The fission products of sugars vary considerably in their potential for browning. Fragments which contain the alpha hydroxycarbonyl group undergo browning alone in aqueous solution and, in the presence of amino acids, browning is accelerated. In a study of non-amino systems, it was shown, by heating various dicarboxylic acids with hydroxymethyl furfural, that an alpha hydroxyl group is required for the occurrence of browning.

4. Aldehydes formed by the Strecker degradation are a possible source of browning. These compounds condense with themselves, with sugar fragments, other dehydration products, or with aldimines and ketimines to form brown pigments. Proteins and amino acids undergo very rapid browning with acetaldehyde but no browning is obtained with formaldehyde. Since glycine which yields formaldehyde by Strecker degradation browns in some cases more and in other cases nearly as rapidly as alanine which yields acetaldehyde, it is apparent that production of aldehydes from alpha amino acids by Strecker degradation could not be a major color producing reaction.
5. In the final stage of browning, intermediate compounds polymerize to form unsaturated colored polymers. Because of similarities in composition and properties of melanoidins derived from the reactions of glycine with glucose, mannose, xylose, furfural or pyruvaldehyde, it was assumed that these melanoidins were derived from similar intermediates. It is now known that there are significant differences among furfural-glycine melanoidin (high content of ether bound oxygen), glucose-glycine melanoidin (high content of alcoholic hydroxyl groups), and pyruvaldehyde-glycine melanoidin (high content of enolic hydroxyl groups and low content of ether bound oxygen). The melanoidins derived from acetaldehyde-glycine or pyruvic acid-glycine give colors different from that of furfural melanoidin, indicating a possible difference in structure.
6. Aldol condensation of pyruvaldehyde has been postulated as the initial reaction in melanoidin formation. Since sugar-amine browning is independent of atmospheric oxygen, reactions are considered proton transfer reactions. However, atmospheric oxidation may

contribute to browning. Some type of oxidation is necessary for the browning of reductones but this need not be supplied by the storage atmosphere. Air oxidation might serve to diminish the extent of color formation by converting the very active compounds such as pyruvaldehyde to less active compounds such as pyruvic acid.

As Hodge indicated, reactions observed in model systems should promote solution to problems in food technology. While the possible relationship of any of the above mentioned reactions to those observed in this study cannot be documented, the observations do serve to indicate possible avenues of investigation.

The fact that storage time was not significant to qualities of flavor and aroma of test samples in this investigation is indicative of the rapid rate of oxidation during packaging under atmospheric oxygen and storage under the various oxygen pressures.

None of the storage variables affected the degree of reconstitution of the test samples. However, there was a significant change in water holding capacity with storage time. Accordingly, storage temperature may play a predominant role in change in the ability of tissues to hold immobilized water. Subjective evaluation of juiciness followed the same pattern as changes in water holding capacity.

The effect of moisture on loss of water holding capacity of samples stored under the various oxygen atmospheres varies. The 2% residual moisture test samples exhibited a progressive loss in water holding capacity with increasing amounts of initial headspace oxygen. In contrast, the 4% residual moisture sample stored in 20% oxygen atmosphere exhibited a greater ability to immobilize water than samples of the same moisture content stored under lower oxygen pressures. This capacity, however, is related to development of the mealy attribute and does not signify an improvement in structural properties. In the mouth, this product seemed to possess the absorbancy of diatomaceous earth at the termination of storage. Conversely, with storage under lower oxygen pressures, the samples with higher residual moisture content expressed more water under pressure than those dried to the lower moisture level. Panelists also implicated storage atmosphere as a factor in development of this extremely dry, mealy characteristic.

Terminal Characteristics

Table XVIII details characteristics at the termination of the storage period. No change in color could be detected in the dehydrated samples. A yellow cast developed in all test samples after rehydration in 176 - 179.6°F water; visually, there was no discernible difference in color among the six test samples.

Only the control samples stored at -10°F in an atmosphere of pre-purified nitrogen failed to exhibit noticeable defects. The primary effect of storage under the lowest oxygen pressure was change in structural characteristics. While other deteriorative changes were observed, variations in flavor and aroma in these samples did not limit storage life.

The variation in rate of development of rancidity in the remaining samples implicates moisture level and indicates that the influence of moisture content on oxidation of both ether extractable and non-ether extractable lipid fractions should be investigated in order to define processing specifications for maximum stability.

RECOMMENDATIONS

At the lowest oxygen pressure, variation in residual moisture content within the 2 to 4% range did not affect product characteristics significantly. Product dried to the lower residual moisture level tolerates somewhat greater amounts of oxygen. The deterioration noted in these samples suggests that exposure to oxygen should be avoided. Since chicken oxidizes readily and molecular oxygen is tightly bound, packaging criteria may not be meaningful in terms of restricting oxidation of bound lipids.

TABLE I

ABSORPTION OF HEADSPACE OXYGEN, ML. PER GRAM

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	0.081	0.081	0.081	0.081	0.081	0.081
	4	0.162	0.162	0.162	0.162	0.162	0.162
	20	0.951	0.951	0.951	0.951	0.951	0.951
4	2	0.083	0.083	0.083	0.083	0.083	0.083
	4	0.166	0.166	0.166	0.166	0.166	0.166
	20	0.852	0.970	0.970	0.970	0.970	0.970
Control	0	0	0	0	0	0	0

TABLE II

CARBON DIOXIDE IN HEADSPACE OF STORAGE CONTAINER, ML. PER GRAM

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	0	0	0	0	0	0
	4	0	0	0	0	0	0
	20	0	0.029	0	0	0	0
4	2	0	0	0	0	0	0
	4	0	0	0	0.018	0	0.018
	20	0.047	0.083	0.030	0.053	0.047	0.018
Control	0	0	0	0	0	0	0

TABLE III

WATER ABSORBED DURING RECONSTITUTION,

PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	148	102	108	147	143	126
	4	117	149	116	131	146	150
	20	150	162	146	139	150	131
4	2	170	160	119	140	169	145
	4	161	127	117	170	169	155
	20	136	125	124	155	138	148

TABLE IV

UNBOUND WATER,

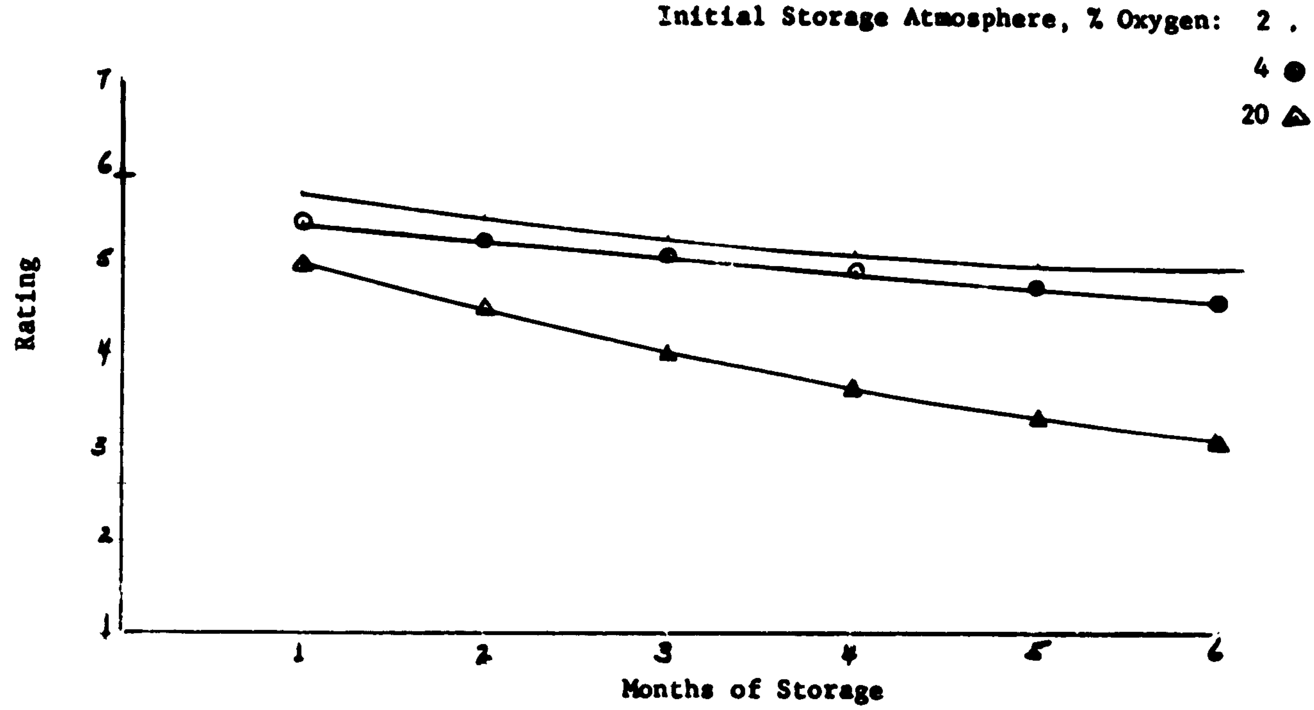
PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	52	40	32	56	52	48
	4	44	59	45	48	58	54
	20	53	68	54	55	58	49
4	2	68	53	40	51	70	59
	4	56	45	44	64	68	74
	20	44	47	46	58	48	58

Figure 1

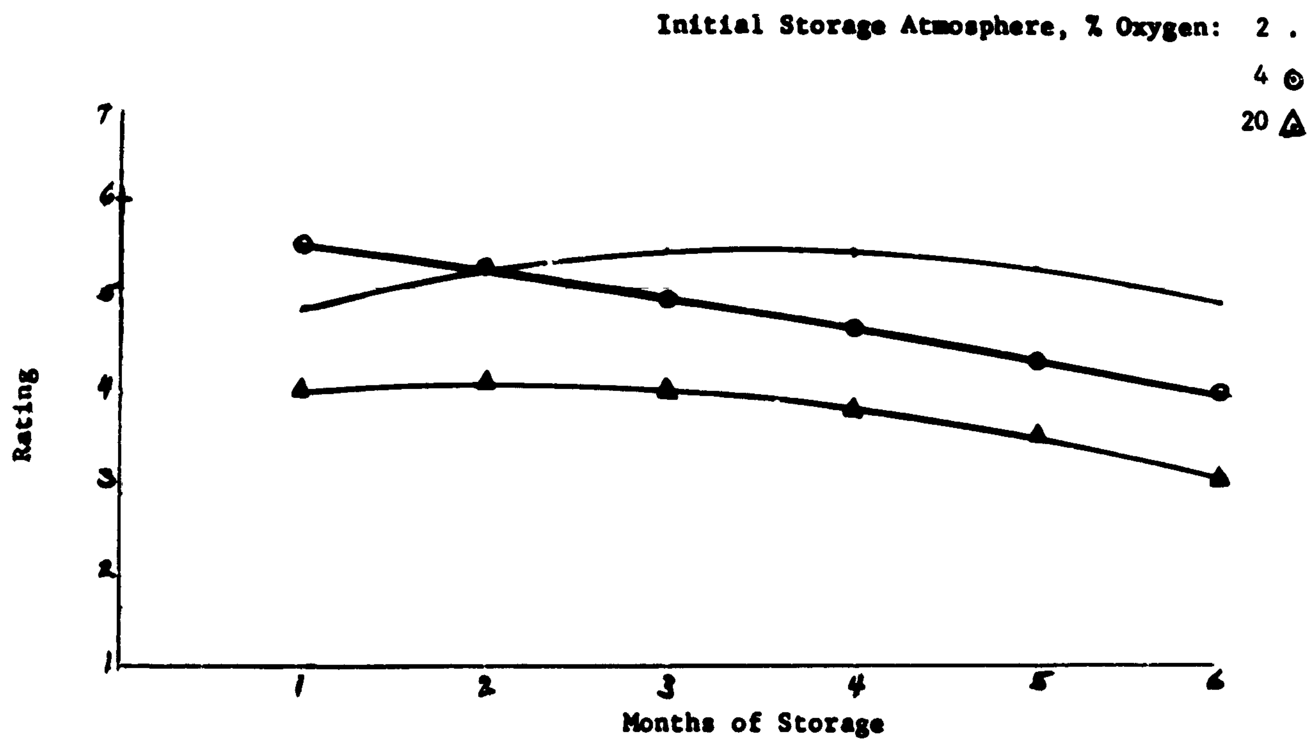
CHICKEN ACCEPTABILITY

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .81; 4%: .23; 20%: .75

B. 4% Moisture Samples

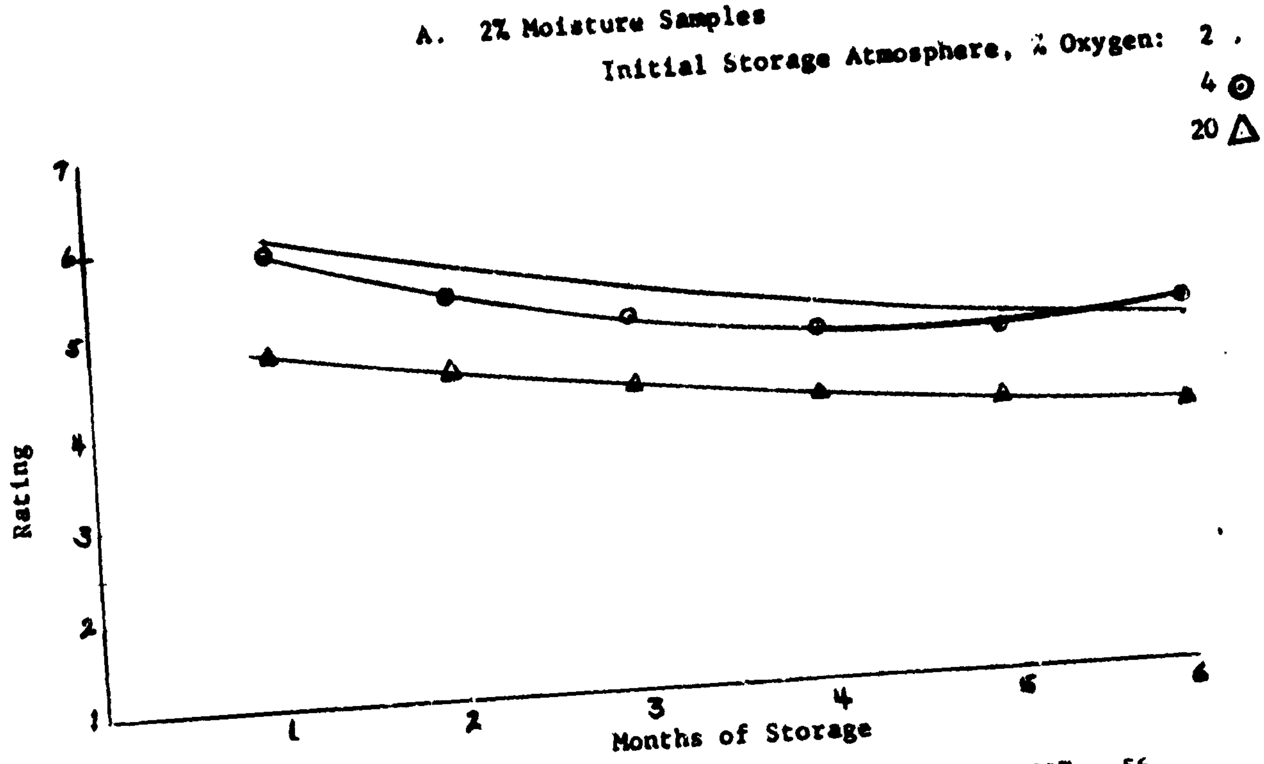


Correlation/Initial Storage Atmosphere - 2%: .77; 4%: .75; 20%: .59

Figure 2

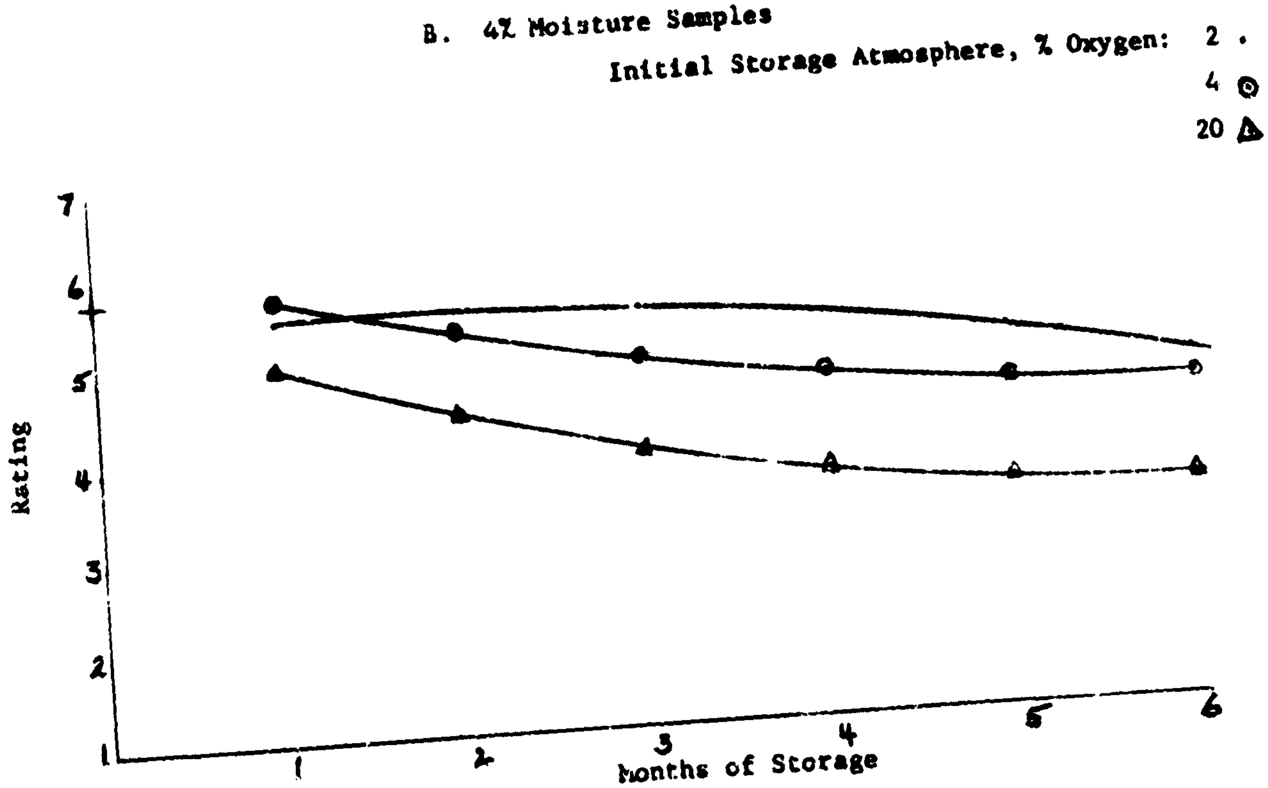
CHICKEN AROMA

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .73; 4%: .47; 20%: .56

B. 4% Moisture Samples

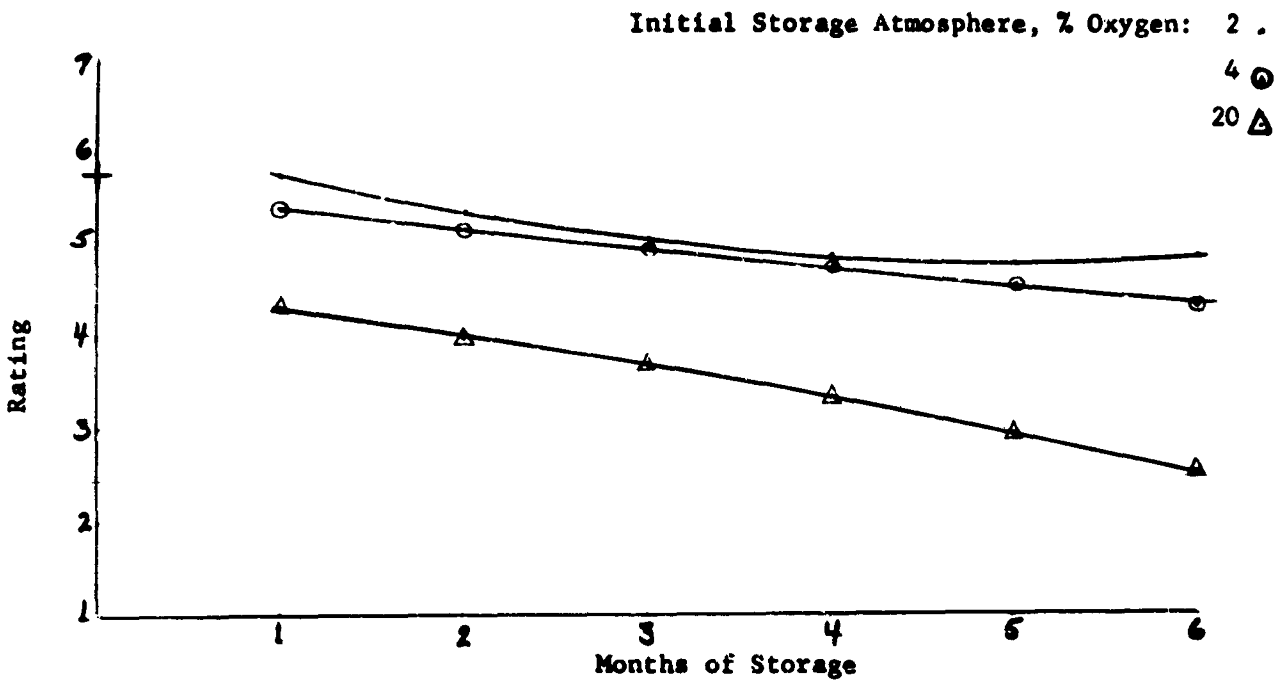


Correlation/Initial Storage Atmosphere - 2%: .62; 4%: .61; 20%: .83

Figure 3

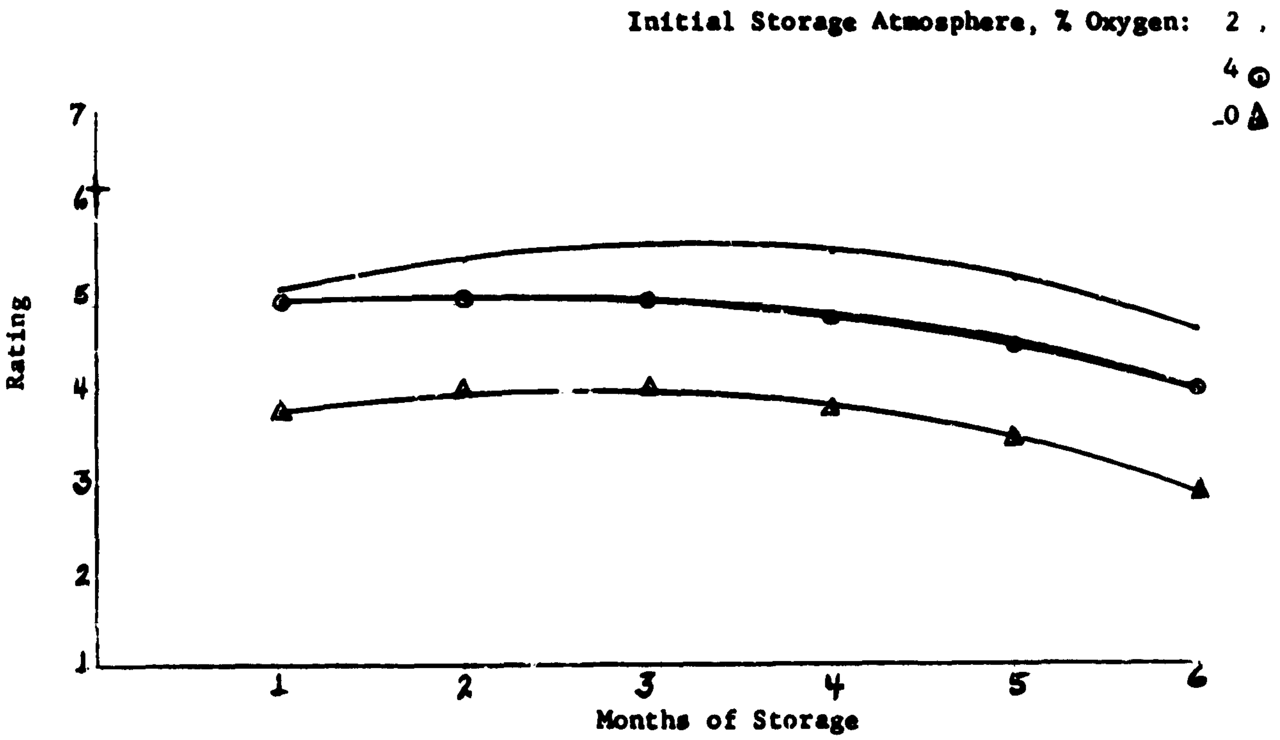
CHICKEN FLAVOR

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .55; 4%: .26; 20%: .73

B. 4% Moisture Samples



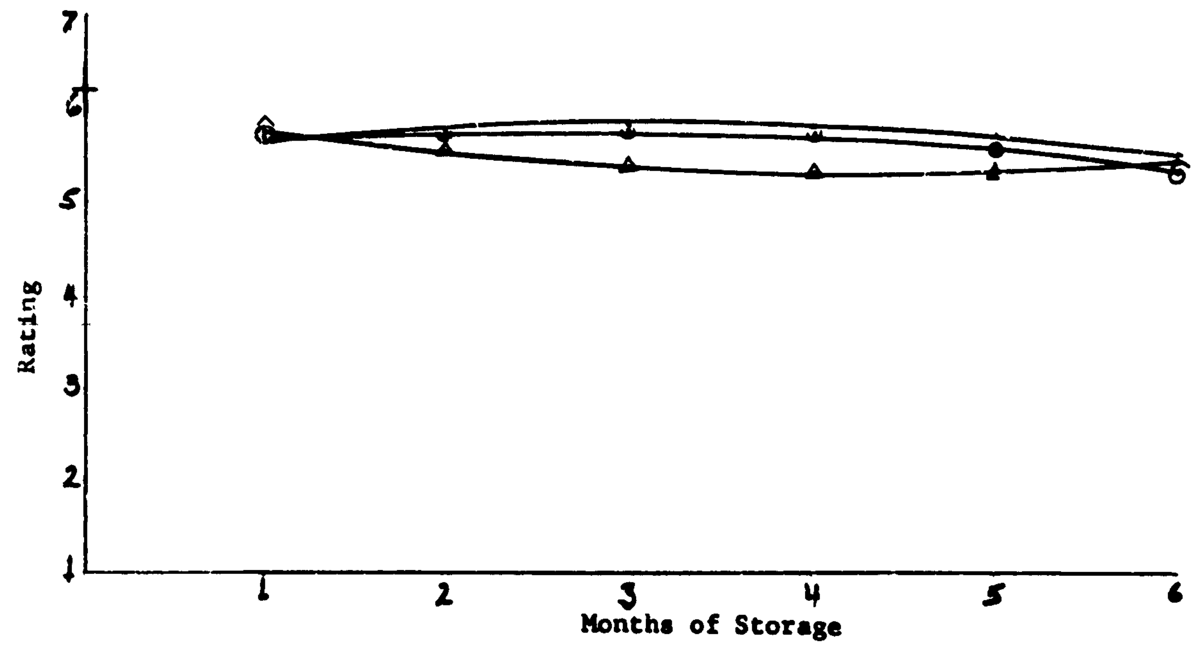
Correlation/Initial Storage Atmosphere - 2%: .97; 4%: .68; 20% .61

Figure 4

CHICKEN TEXTURE

A. 2% Moisture Samples

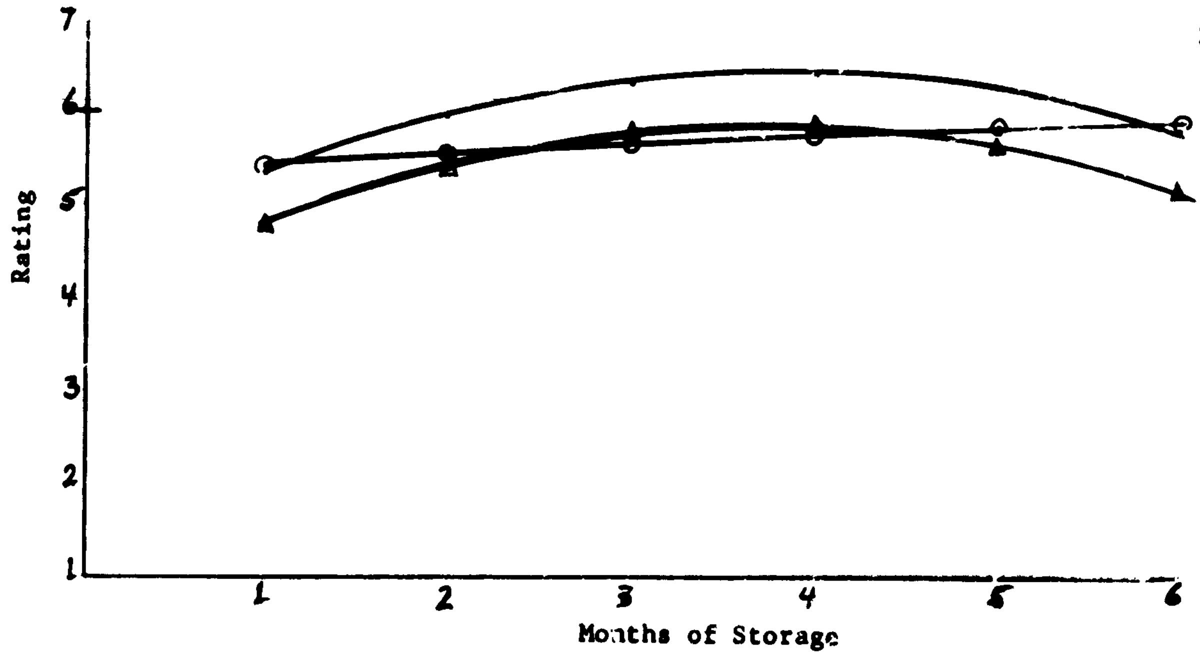
Initial Storage Atmosphere, % Oxygen: 2
4
2?



Correlation/Initial Storage Atmosphere - 2%: .28, 4%: .36; 20%: .29

B. 4% Moisture Samples

Initial Storage Atmosphere, % Oxygen: 2
4
20

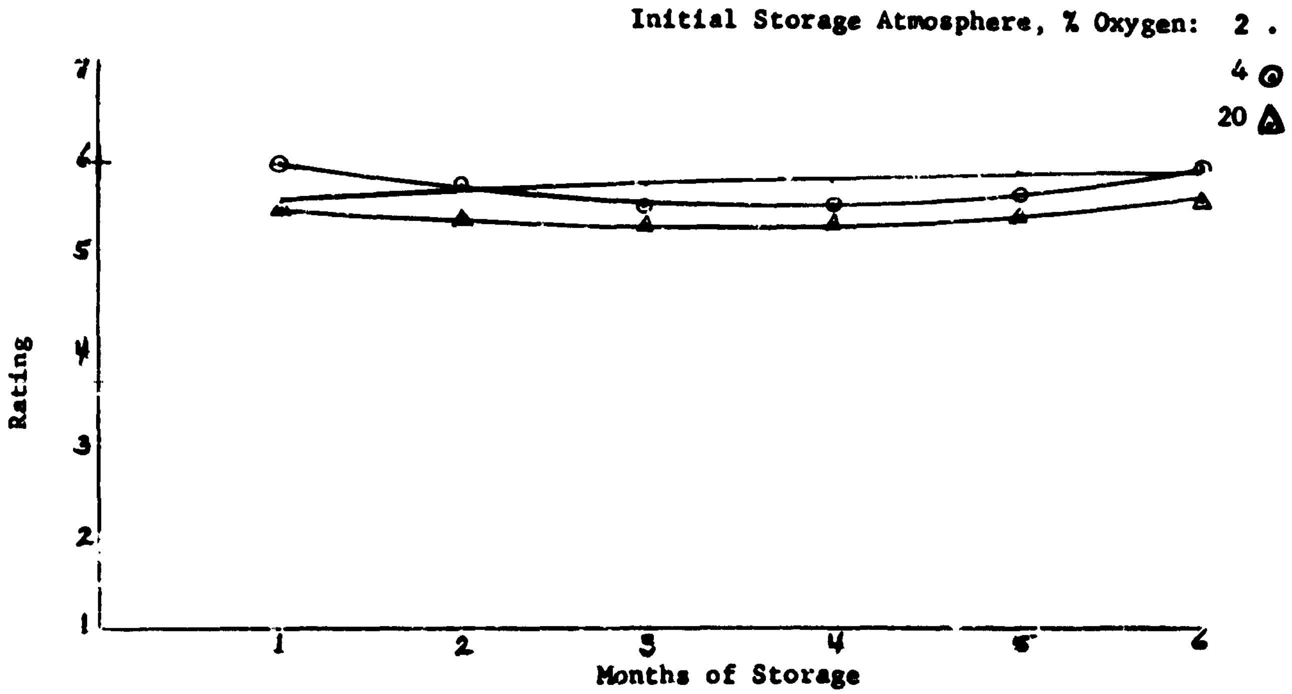


Correlation/Initial Storage Atmosphere - 2%: .84; 4%: .52; 20%: .87

Figure 5

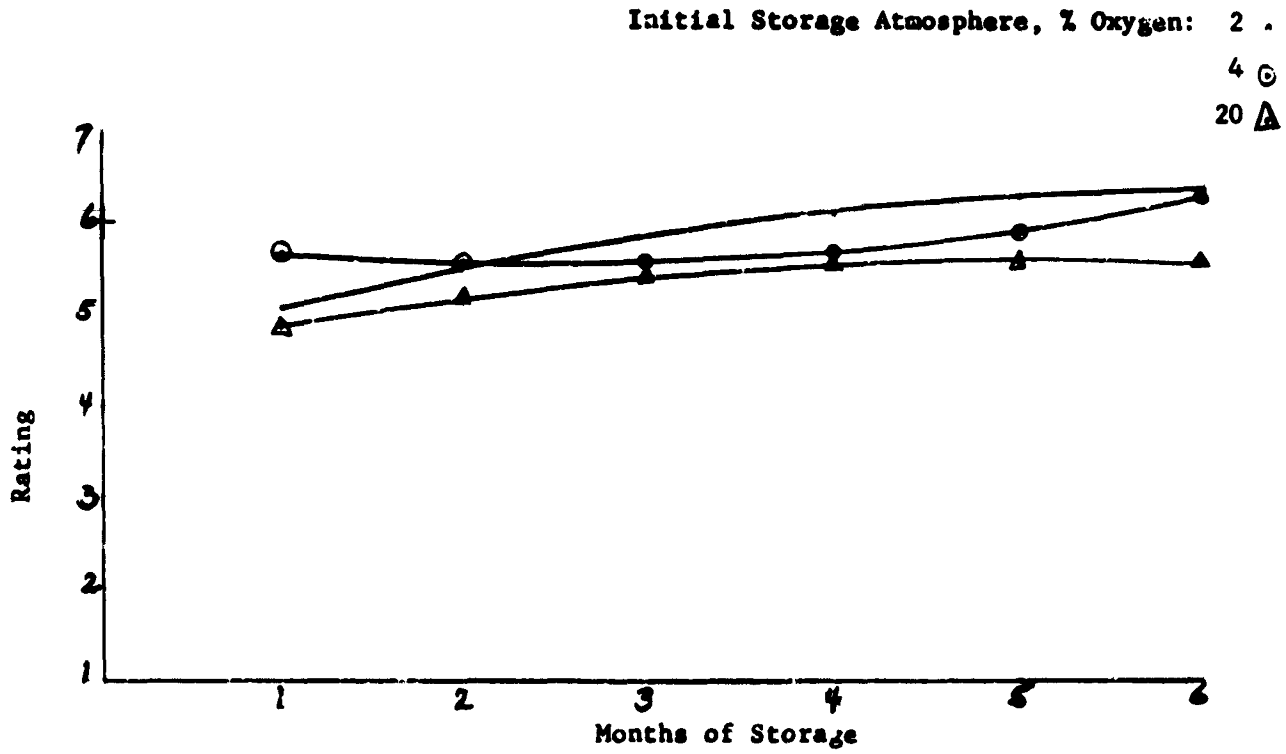
CHICKEN JUICINESS

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2: .26· 4: .53, 20: .28

B. 4% Moisture Samples



Correlation/Initial Storage Atmosphere - 2: .91, 4: .73, 20: .60

TABLE V

SUMMARY OF STATISTICAL ANALYSES

Test	Source of Variation	Sensory Judgments					Rehydration Measurements	
		Acceptability	Aroma	Flavor	Texture	Juiciness	Total Water Absorbed	Unbound Water
Analysis of Variance	Moisture, M							
	Oxygen, O	**	**	**	*	**		
	Storage Time, T	**				**		*
	MO							*
	MT				*	*		
	OT							
Multiple Range	Initial Headspace Oxygen, Percent	*** 264/20	*** 2/20	*** 264/20	*** 2/20	*** 264/20		

* p = .05

** p = .01

*** p = .005

TABLE VI

ANALYSIS OF VARIANCE: CHICKEN ACCEPTABILITY

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.20718	.20718	1.17
Oxygen, O	2	13.34467	6.67234	37.83 **
Storage Time, T	5	5.71558	1.14312	6.48 **
MO	2	.04764	.0238	.13
MT	5	1.14488	.22898	1.30
OT	10	1.98687	.19869	1.13
MOT (Error)	10	1.76372	.17637	
TOTAL	35	24.21054		

TABLE VII

ANALYSIS OF VARIANCE: CHICKEN AROMA

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.11111	.11111	.21
Oxygen, O	2	9.26995	4.63497	8.71 **
Storage Time, T	5	7.69118	1.53823	2.89
MO	2	.11423	.05711	.11
MT	5	.74806	.14961	.28
OT	10	1.63552	.16355	.31
MOT (Error)	10	5.31957	.53196	
TOTAL	35	24.88962		

TABLE VIII

ANALYSIS OF VARIANCE: CHICKEN FLAVOR

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.00035	.00035	.00
Oxygen, O	2	16.79034	8.39517	12.98 **
Storage Time, T	5	5.90744	1.18148	1.83
MO	2	.19730	.09865	.15
~~MT~~	~~5~~	~~1.72123~~	~~.34424~~	~~.53~~
OT	10	1.46672	.14667	.23
MOT (Error)	10	6.46910	.64691	
TOTAL	35	32.55248		

TABLE IX

ANALYSIS OF VARIANCE: CHICKEN TEXTURE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.06199	.06199	.84
Oxygen, O	2	1.10553	.55276	7.47 *
Storage Time, T	5	.91657	.18331	2.48
MO	2	.18125	.09063	1.23
MT	5	1.26745	.25349	3.43 *
OT	10	.38317	.03832	.52
MOT (Error)	10	.73951	.07395	
TOTAL	35	4.65547		

TABLE X

ANALYSIS OF VARIANCE: CHICKEN JUICINESS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.01862	.01862	.48
Oxygen, O	2	1.22820	.61410	15.69 **
Storage Time, T	5	1.17000	.23400	5.98 **
MO	2	.03689	.01844	.47
MT	5	.80404	.16080	4.10 *
OT	10	.97122	.09712	2.48
MOT (Error)	10	.39130	.03913	
TOTAL	35	4.62027		

TABLE XI

ANALYSIS OF VARIANCE: WATER ABSORBED DURING RECONSTITUTION,

PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.07747	.07747	2.37
Oxygen, O	2	.00474	.00237	.07
Storage Time, T	5	.35505	.07101	2.17
MO	2	.15124	.07562	2.31
MT	5	.05851	.01170	.36
OT	10	.16839	.01684	.51
MOT (Error)	10	.32723	.03272	
TOTAL	35	1.14263		

TABLE XII

ANALYSIS OF VARIANCE: UNBOUND WATER,

PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.01361	.01361	2.68
Oxygen, O	2	.00545	.00273	.54
Storage Time, T	5	.08850	.01770	3.49 *
MO	2	.04567	.02284	4.50 *
MT	5	.03442	.00688	1.36
OT	10	.06705	.00671	1.32
MOT (Error)	10	.05070	.00507	
TOTAL	35	.30540		

TABLE XIII

CHICKEN ACCEPTABILITY, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
	2	5.725	5.375	5.300	5.200	4.750	5.094
2	4	5.600	5.150	4.150	5.800	4.675	4.375
	20	5.250	4.125	3.500	4.250	3.350	2.812
	2	4.875	5.200	5.400	5.675	5.050	4.950
4	4	5.250	5.850	4.675	4.375	4.425	3.925
	20	4.050	3.800	3.950	4.225	2.925	3.150

TABLE XIV

CHICKEN AROMA, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage					
		1	2	3	4	5	6
2	2	6.150	5.350	5.550	5.350	4.300	4.812
	4	6.000	5.450	4.200	5.425	4.900	4.625
	20	4.900	4.400	3.900	4.650	3.600	3.812
4	2	5.500	5.700	5.350	5.700	4.650	4.850
	4	5.500	6.000	4.700	4.300	4.850	4.400
	20	4.900	4.600	3.900	3.925	2.950	3.600

TABLE XV

CHICKEN FLAVOR, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage					
		1	2	3	4	5	6
2	2	5.575	5.575	5.125	5.000	4.200	5.156
	4	5.625	5.075	3.975	5.825	4.450	4.125
	20	4.300	4.100	3.250	3.975	2.525	2.656
4	2	5.050	5.300	5.575	5.475	5.075	4.625
	4	4.750	5.325	4.800	4.400	4.700	3.900
	20	3.900	3.625	3.800	4.375	3.100	2.850

TABLE XVI

CHICKEN TEXTURE, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	5.650	5.800	5.825	6.050	5.400	5.656
	4	5.800	5.400	5.875	6.000	5.475	5.343
	20	5.850	5.400	5.325	5.750	4.950	5.531
	2	5.375	5.950	6.200	6.300	6.575	5.650
	4	5.250	5.850	5.600	5.600	5.850	5.900
	20	4.800	5.300	5.800	5.975	5.350	5.250

TABLE XVII

CHICKEN JUICINESS, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	5.625	5.500	5.875	5.500	6.125	5.781
	4	6.100	5.300	5.675	5.500	5.625	5.[illegible]
	20	5.600	5.050	5.300	5.500	5.325	5.531
	2	5.200	5.300	5.725	6.150	6.450	6.225
	4	5.550	5.825	5.425	5.500	5.950	6.225
	20	4.900	5.000	5.525	5.750	5.200	5.675

TABLE XVIII

PRODUCT DESCRIPTION,

TERMINATION OF STORAGE

Residual Moisture, Percent	Initial Headspace Oxygen Percent	Dehydrated		Rehydrated				
		Aroma	Appearance	Aroma	Appearance	Flavor	Texture	Juiciness
2	2	Sharp Chicken	Typical	Sharp Chicken	Yellow Cast	Sharp Chicken	Moderately Tough	Fairly Dry
	4	Putrid Chicken	Typical	Chicken, Ammonia	Yellow Cast	Sharp Chicken	Moderately Tough	Fairly Dry
	20	Rancid	Typical	Chicken, Slight Rancid	Yellow Cast	Rancid	Moderately Tough	Very Dry
4	2	Sharp Chicken	Typical	Sharp Chicken	Yellow Cast	Sharp Chicken	Moderately Tough	Fairly Dry
	4	Putrid Chicken	Typical	Flat	Yellow Cast	Chicken, Slight Rancid	Moderately Tough	Moderately Dry
	20	Rancid	Typical	Chicken, Moderately Strong Rancid	Yellow Cast	Putrid, Rancid	Moderately Tough, Spongy	Very Dry Mealy
2*	0	Odorless	Typical	Boiled Chicken	No Yellow Cast	Boiled Chicken	Moderately Tender	Fairly Juicy

* Storage Temperature: -10°F

III. CARROTS

There is a dearth of information relating characteristics of freeze-dehydrated carrots to storage environment. The investigations conducted to date have dealt largely with the effect of processing and packaging variables on stability of conventionally dehydrated carrots. While the type of dehydrative process is a significant factor, certain gross characteristics may typify reactions of the product, regardless of method of dehydration.

The oxidation of carotenoid pigments in plant tissues during processing or storage is one of the factors responsible for impairment of quality attributes. The oxidation of beta carotene to beta ionone causes undesirable hay-like flavors and odors and loss of color. (Barnell, et al, 1955).

According to Mackinney, et al (1958), the necessity of excluding oxygen from the storage atmosphere of conventionally dehydrated carrots has been reaffirmed repeatedly. Investigation indicated that oxygen absorption must be limited to 0.1 ml. oxygen per gram of product conventionally dried to the 5% residual moisture level if off-flavors were to be avoided. However, oxygen consumption is known to be a function of moisture content. While reactions other than carotene oxidation compete for available oxygen supply in a sealed container, progressive lowering of moisture content from 5 to 2% can result in substantially more carotene oxidation at such an oxygen-product ratio during storage.

A study of the effect of storage in nitrogen and air atmospheres on stability of soup mixes containing freeze-dried vegetables indicated that the protection afforded by nitrogen lessened during storage. It was suggested that undesirable off-flavors were eventually destroyed to some extent in air stored samples while concentration increased in nitrogen stored samples (Wuhrmann, et al, 1959).

Research conducted by British workers indicated that the reaction between amino acids and organic acids does not contribute appreciably to browning of conventionally dehydrated carrots. However, this reaction did augment the initial rate of browning and altered the course of browning reaction during later stages since a decrease in water soluble brown pigment was noted. As the result of this work, it was postulated that the reducing sugar-amino acid browning reaction is responsible for 95 percent of the browning in conventionally dehydrated carrots. This browning appeared to involve all amino acids to the same extent, resulting in a general reduction in quantity of identified compounds (Barnell, et al, 1955).

The effect of residual moisture content and storage atmosphere on browning reaction in conventionally dehydrated carrots was investigated by Legault, et al (1951). Nonenzymic browning reaction was the principal deteriorative process at elevated storage temperatures. Drying the product to low residual moisture content afforded substantial protection against browning reaction. At a storage temperature of 100°F, the rate of browning reaction decreased by 1.6 fold with reduction in residual moisture content from 6.5 to 4.0%. Storage atmosphere, whether nitrogen or air, was reported to have little effect on the rate of browning.

RESULTS AND DISCUSSION

Oxygen Absorption

The absorption of headspace oxygen by precooked, freeze-dehydrated carrots is shown in Table I. In general, the rate of absorption is high initially and decreases with storage time. However, there is a terminal increase in rate of oxygen absorption by the 4% residual moisture samples stored under 4 and 20% oxygen atmospheres. The amount of oxygen absorbed is dependent on the residual moisture content. Paired comparison of oxygen absorption under the various atmospheres revealed that samples dried to the lower residual moisture level absorb significantly greater amounts of oxygen than samples dried to the higher residual moisture level. Significance level varied with the initial headspace oxygen content. The difference in amount of oxygen absorbed was significant at the .001 level of probability for the samples stored under 2 and 20% oxygen atmospheres and at the .01 level of probability for samples stored under 4% oxygen atmosphere.

Carbon Dioxide Production

The reactions occurring in samples dried to the 4% residual moisture level produced a substantially greater amount of carbon dioxide than those in the lower moisture content samples. Carbon dioxide was detected in each headspace atmosphere sample withdrawn from the 4% residual moisture samples. In contrast carbon dioxide was present only in the 20% oxygen headspace atmospheres of 2% residual moisture samples. Carbon dioxide production is shown in Table II.

Rehydration Characteristics

Tables III and IV show the relative rehydration and unbound water content in the test samples. While use of the press technique for measurement of easily expressed or unbound water has been reported repeatedly for meat products, this technique does not appear to have been applied to vegetable products. Applicability of this method of measurement or modifications thereot is uncertain. The inherent variance among individual specimens described in previous sections of this report applies equally well to this product and to validity of these physical measurements.

Quality Attributes

Figures 1 through 6 show the trends in changes in quality attributes during storage. Sensory judgments of aroma, flavor, and color tend to parallel that of acceptability. The 2% residual moisture samples appeared to be relatively more stable in these characteristics during storage. A deteriorative reaction was much more apparent in attributes of the 4% residual moisture samples.

Statistical Analyses

Table V summarizes the statistical analyses of sensory judgments and rehydration measurements. Analyses of variance of the sensory characteristics are shown in Table VI through XI and those of physical measurements of rehydration characteristics in Tables XII and XIII. The mean values of panelists' scores for the sensory qualities are presented in Tables XIV through XIX.

Storage atmosphere was the most significant factor in deterioration of quality attributes of precooked, freeze-dehydrated carrots. The oxidative effect increased with content of oxygen in the headspace of the storage container. Regardless of moisture content, carrots stored in 20% oxygen atmospheres exhibited marked loss of carotene and development of undesirable flavor and aroma at the first evaluation of the test samples. Among the stored samples, the oxidative deterioration incident to storage under a 2% oxygen headspace atmosphere was not significant. Oxygen labile compounds such as carotene are relatively stable if contact with molecular oxygen is limited during packaging operations and oxygen content of the storage vessel is severely restricted. However, deteriorative reactions do occur and, for procurement purposes, it appears desirable to document the relative effect of exposure to atmospheric oxygen during packaging operations and of storage under very low oxygen partial pressures on stability at elevated temperatures.

The fact that storage time was less important to quality attributes during storage was considered significant and was attributable to the rate of adsorption of headspace oxygen and consequent deterioration during the initial storage period. The magnitude of these changes overshadowed the slight but progressive degradation during the remainder of the storage period. At no time during this investigation were the aroma and flavor of samples stored in 20% oxygen atmospheres judged superior to those of samples stored under lower oxygen concentrations.

Moisture did not appear to be an important factor in storage stability. Failure to implicate residual moisture content was evidence of the distinctive reactions characteristic of the two moisture levels. There is every indication that the characteristics ascribed to oxidation and browning reaction at the higher residual moisture level are just as objectionable over the storage period as those ascribed to pronounced oxidation at the lower residual moisture level.

Residual moisture content exerted a slight effect on retention of color. While the effect was not great enough to be considered significant at the probability levels used, better color retention by the 4% moisture samples stored under the lowest oxygen pressure may be of practical significance.

Residual moisture content did moderate the deteriorative reactions. Some oxidative reactions are facilitated by drying to low residual moisture levels. Conversely, browning reaction was observed only in those samples dried to the higher residual moisture level. In terms of visual color change concurrent with loss of color through oxidation of carotene, browning reaction was not severe. Accordingly, the effect of moisture on flavor varied with storage time and progress of the specific deteriorative reaction. The effect of interaction of moisture and time variables was also noted in analysis of acceptability ratings; however, the effect was not significant at the levels selected for these analyses.

The relationship between storage atmosphere and progress of browning reaction could not be determined in the absence of chemical analyses.

The structural qualities were also impaired during storage. These changes were not as serious as those associated with storage of protein foods under adverse conditions.

Oxygen affected water holding capacity. Samples stored under the lowest oxygen concentration expressed water more easily under pressure than did those stored under 4 and 20% oxygen atmospheres. In general, objective measurements supported subjective judgments. However, the effect of storage under 20% oxygen atmosphere was confounded by the development of an oily characteristic. This characteristic was not measured objectively.

The effect of moisture on degree of reconstitution differs with initial headspace atmosphere. Under the lowest oxygen concentration, the 4% residual moisture samples absorbed a greater amount of water. Under higher oxygen concentrations, this effect was reversed. Analysis suggests that this moisture was easily expressed under pressure. Water holding capacity appeared to be similar for samples stored under 2% oxygen atmosphere. In contrast, under higher oxygen concentrations, samples processed to the 4% residual moisture level exhibited greater water holding capacity.

The ability to immobilize water varied considerably over the storage period. Average sensory ratings of juiciness and texture showed an inverse relationship to the amount of water expressed under pressure. Relative agreement between subjective and objective measurements of water holding capacity is indicative of the merit of applying this technique to well-structured vegetables such as carrots. More data are required to verify the agreement and to determine benefit of modification of technique.

Terminal Characteristics

Table XX describes product characteristics at the termination of storage. Characteristics of freeze-dried carrots appear to be similar to those reported for conventionally dehydrated carrots. Visibly discernible browning occurred only in samples processed to the higher residual moisture content. These products were characterized by acidic odors and somewhat sweet flavors. These changes indicated hydrolysis of some fractions of the product. Relative increase in sweetness might be attributable to conversion of starch or polysaccharides during storage. The oily character of the 4% residual moisture sample stored under 20% oxygen atmosphere indicated the possibility of hydrolysis of the fatty acid esters to fatty acids and glycerol. No rancid note was detected. However, glycerol is relatively stable to oxidation. A sweet taste is also typical of this compound. Mevalonic acid is among the breakdown products of beta carotene (Braverman, 1963). This compound is also an oily liquid (The Merck Index, 1960). However, sufficient quantity to account for this reaction is improbable. Lack of an oily characteristic in samples processed to the 2% residual moisture level and stored in 20% oxygen atmosphere which exhibited pronounced carotene oxidation also indicated that this compound did not account for the oily characteristic.

No browning could be detected in samples dried to the lower residual moisture level. As indicated, these samples exhibited yellow to orange colors and hay-like odors and flavors on oxidation.

Magnitude of these changes in quality attributes was dependent on headspace oxygen concentration. Carotene loss in products stored under a 2% oxygen atmosphere appeared slight.

The variation in reaction characteristics indicates that product dried to the higher moisture level and stored with little or no exposure to atmospheric oxygen should not be reconstituted as specified, i.e., with the addition of sucrose to the rehydration medium.

RECOMMENDATIONS

The product can tolerate limited exposure to atmospheric oxygen and storage under 2% oxygen atmosphere without evidencing extreme deterioration. Despite the differences in reactions at the two residual moisture levels, there did not appear to be any difference between the moisture levels in stability of product. Consequently, it would be of interest to determine whether a moisture content midway between those investigated would prove more satisfactory from the standpoint of storage stability.

TABLE I

ABSORPTION OF HEADSPACE OXYGEN, ML. PER GRAM

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	0.25	0.46	0.46	0.46	0.46	0.46
	4	0.59	0.51	0.89	0.89	0.89	0.89
	20	2.54	3.00	3.03	3.23	3.21	2.93
4	2	0.08	0.00	0.10	0.18	0.21	0.21
	4	0.24	0.31	0.34	0.18	0.63	0.52
	20	1.00	1.73	1.89	1.92	2.02	2.23
Control	0	0	0	0	0	0	0

TABLE II

CARBON DIOXIDE IN HEADSPACE OF STORAGE CONTAINER, ML. PER GRAM

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	0	0	0	0	0	0
	4	0	0	0	0	0	0
	20	0.38	0.33	0.38	0.51	0.64	0.48
4	2	0.08	0.08	0.21	0.29	0.34	0.24
	4	0.16	0.08	0.08	0.21	0.26	0.13
	20	0.29	0.50	0.58	0.66	0.89	0.87
Control	0	0	0	0	0	0	0

TABLE III

WATER ABSORBED DURING RECONSTITUTION,

PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage					
		1	2	3	4	5	6
2	2	729	744	715	800	721	704
	4	768	742	768	798	732	775
	20	754	747	725	781	766	706
4	2	~~778~~	~~743~~	~~773~~	~~835~~	~~812~~	~~789~~
	4	711	750	791	726	775	750
	20	762	672	689	774	748	771

TABLE IV

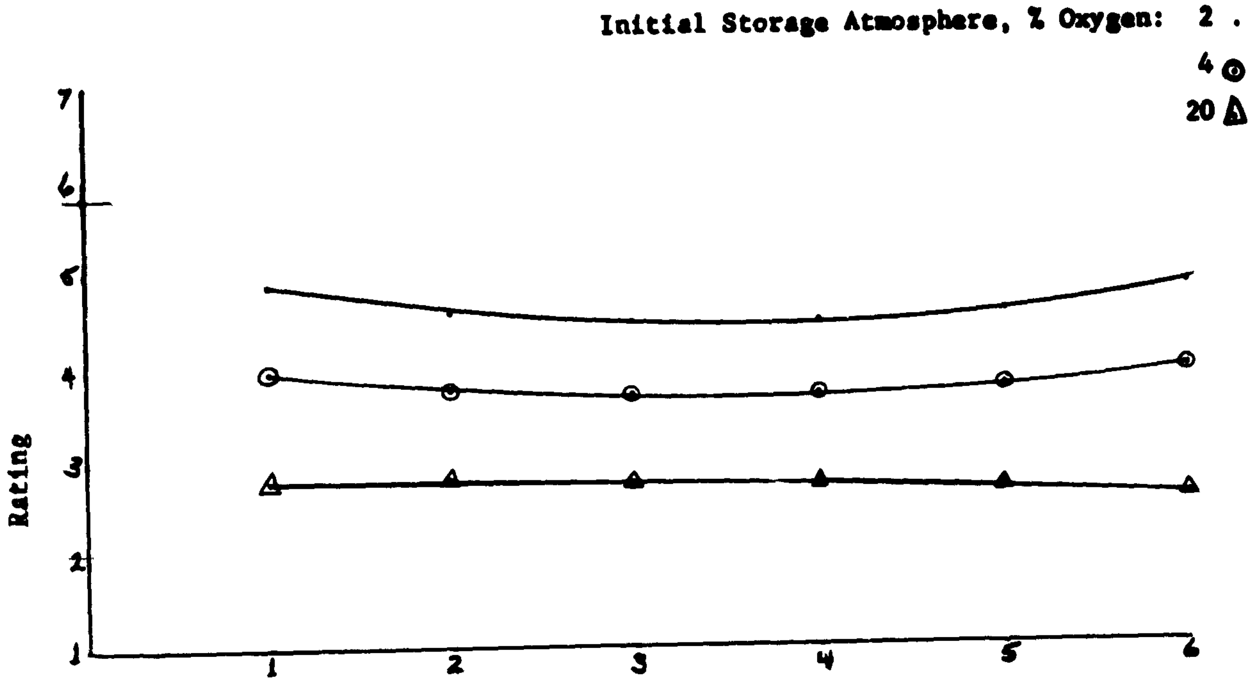
UNBOUND WATER,

PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage					
		1	2	3	4	5	6
2	2	547	509	501	603	495	441
	4	556	506	523	562	375	499
	20	561	532	496	538	429	403
4	2	609	544	525	646	475	623
	4	468	469	444	421	410	412
	20	465	320	383	564	496	498

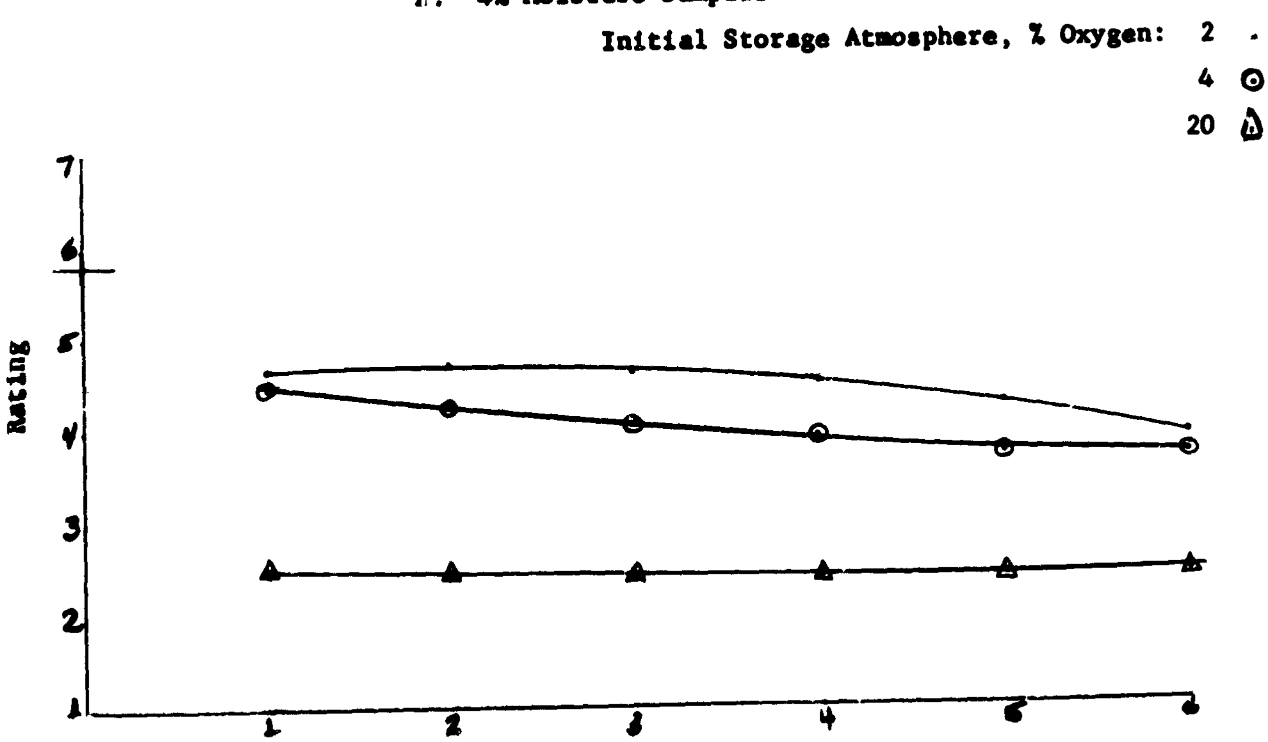
CARROT ACCEPTABILITY

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .64; 4%: .09; 20%: .09

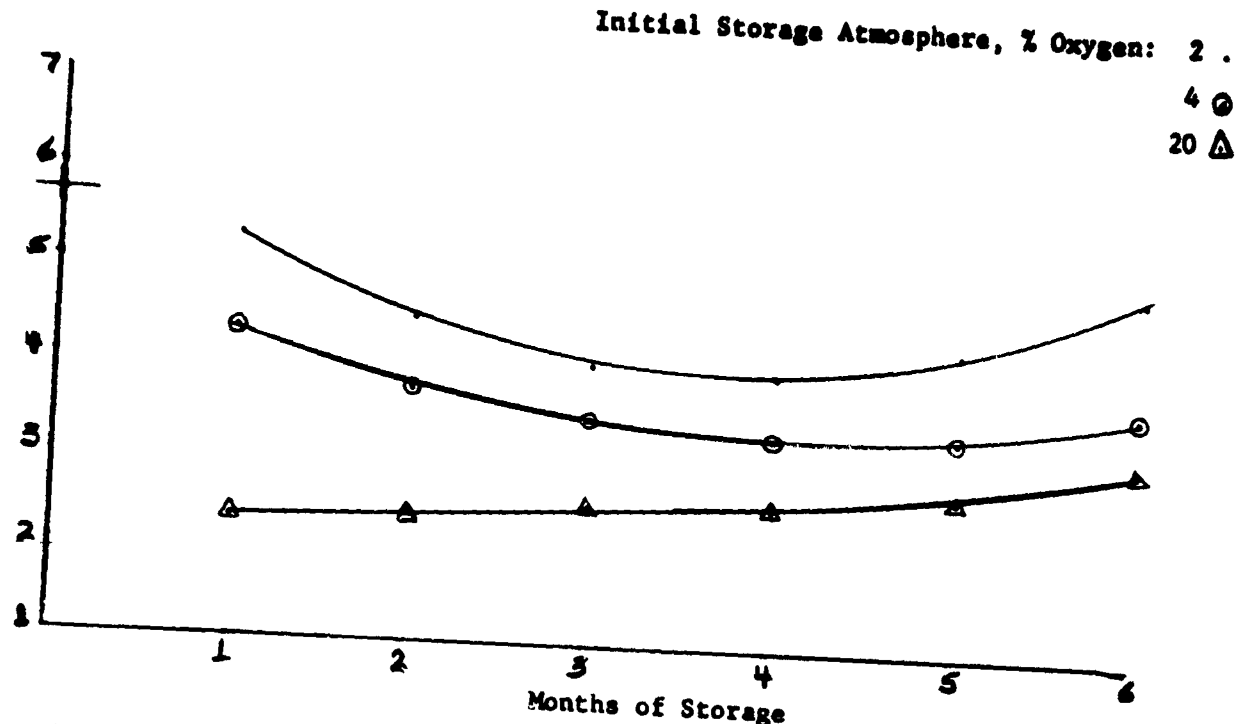
B. 4% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .35; 4%: .66; 20%: .004

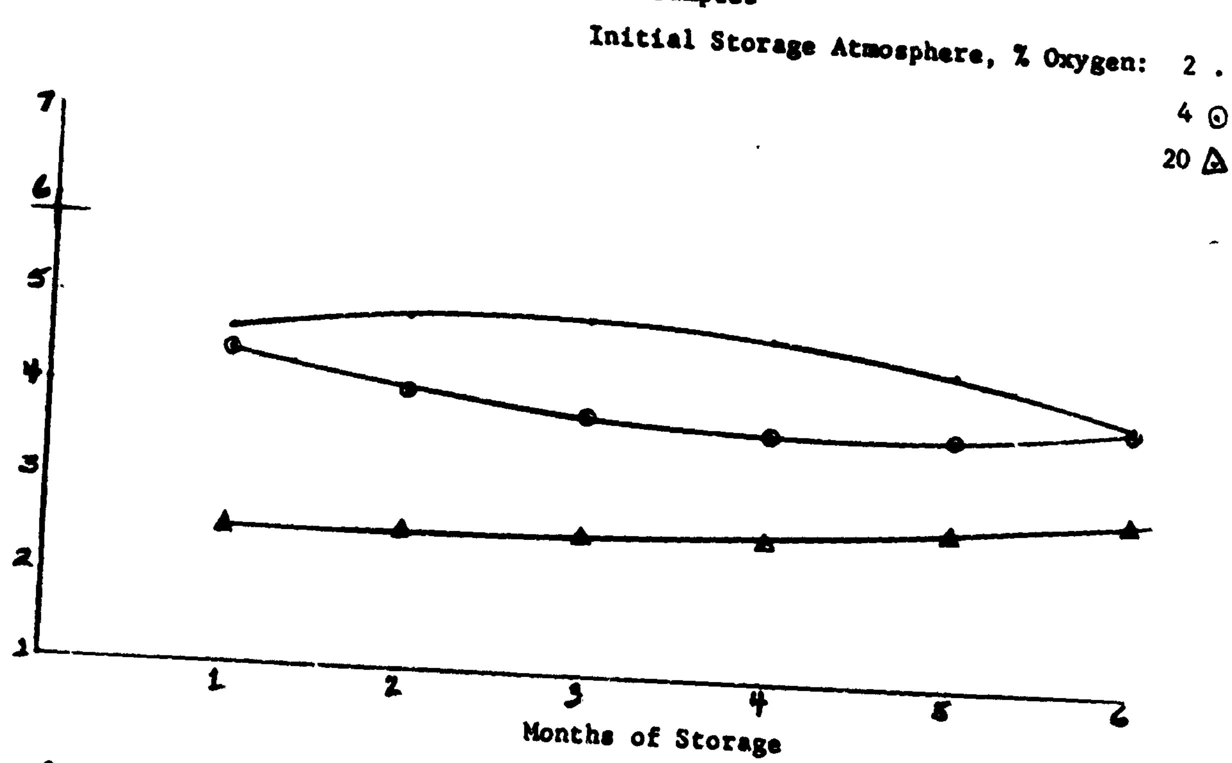
CARROT AROMA

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .75; 4%: .21; 20%: .25

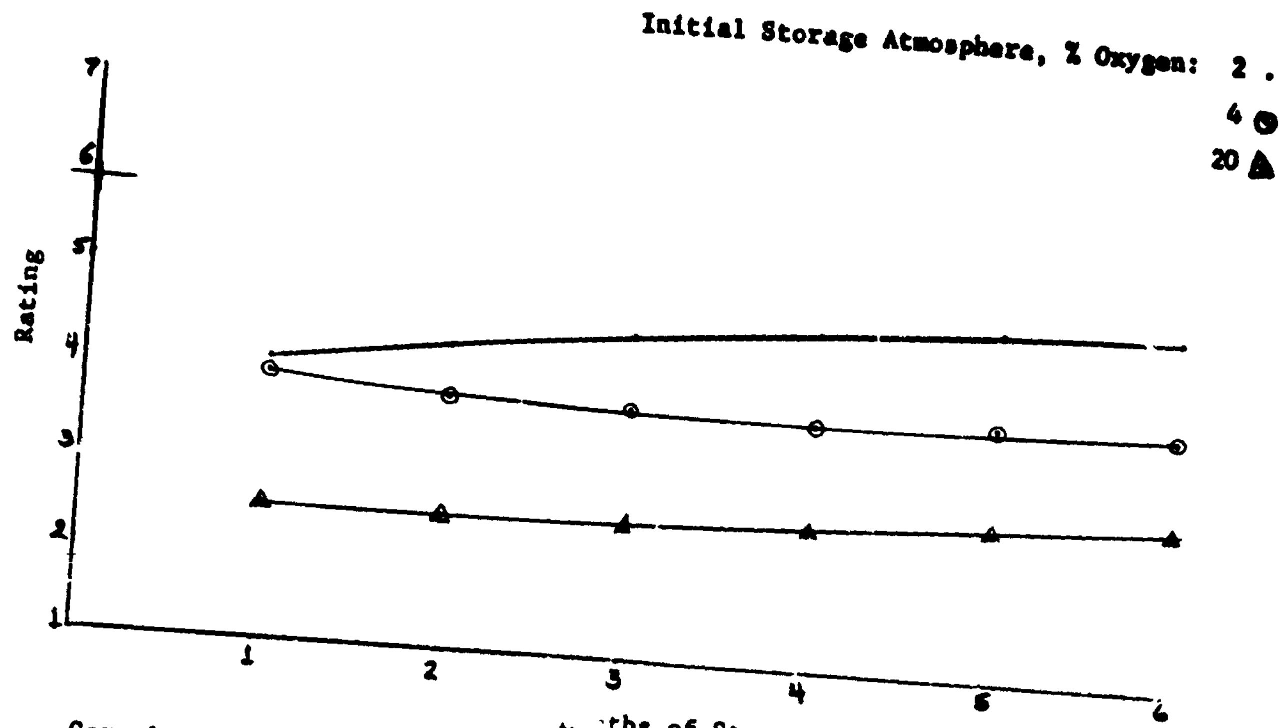
B. 4% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .58; 4%: .58; 20%: .26

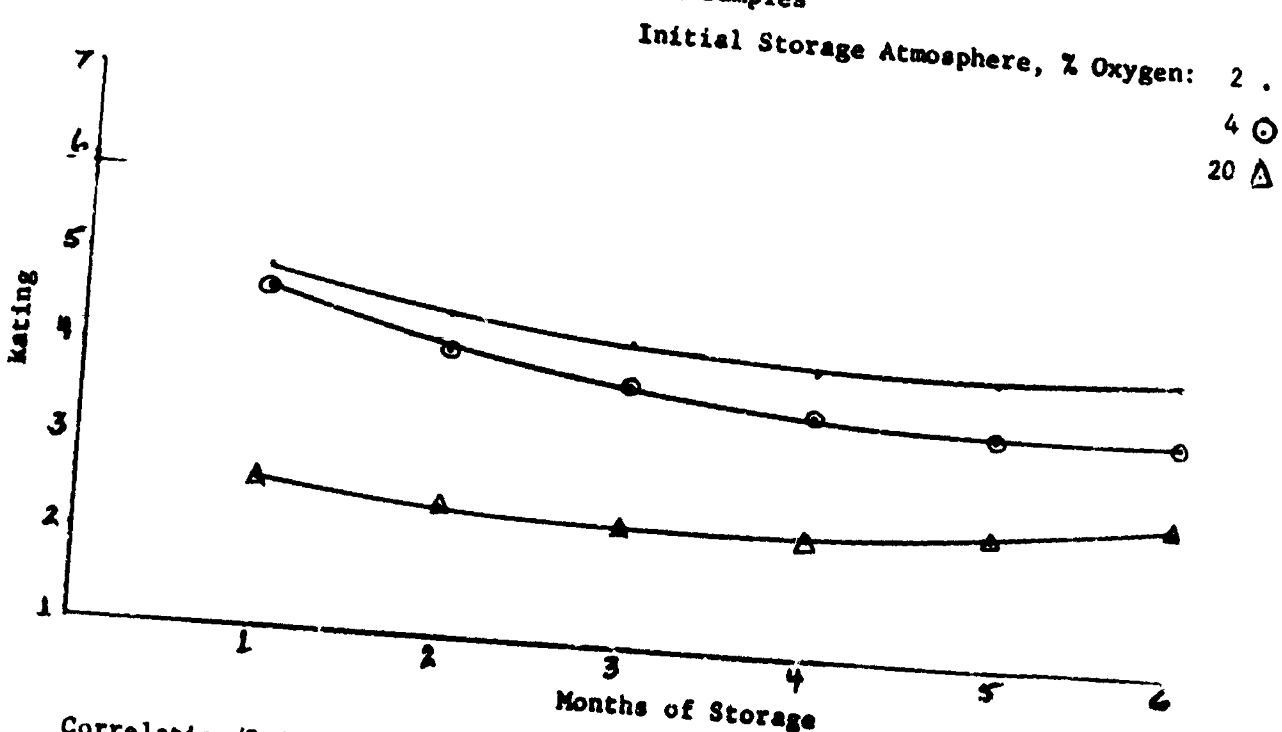
CARROT FLAVOR

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphe.. - 2%: .63; 4%: .03; 20%: .36

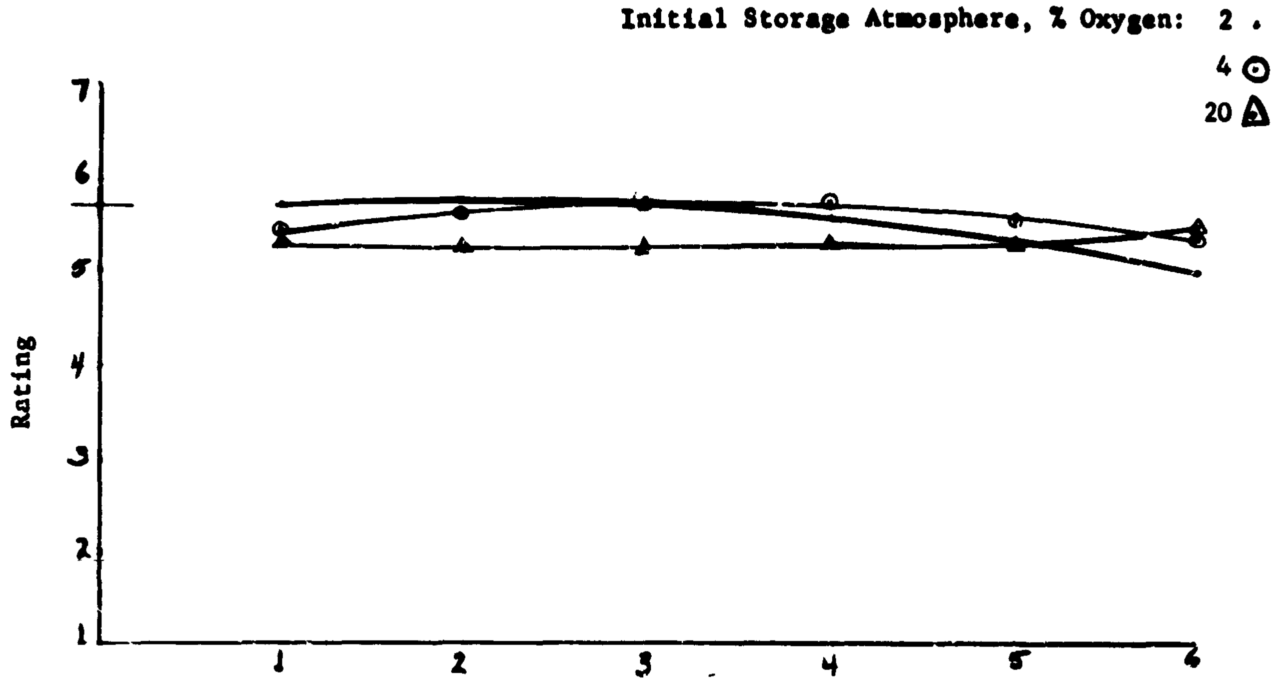
B. 4% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .38; 4%: .62; 20%: .12

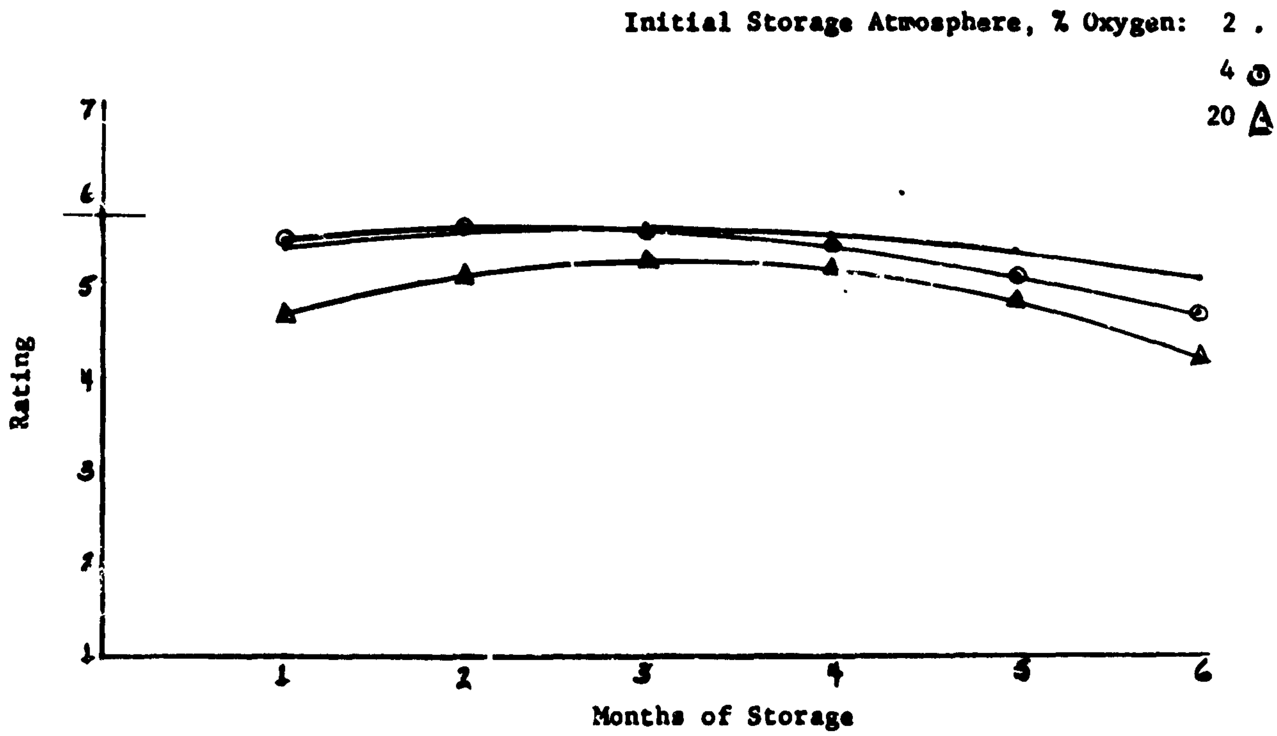
CARROT TEXTURE

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .77; 4%: .11; 20%: .18

B. 4% Moisture Samples

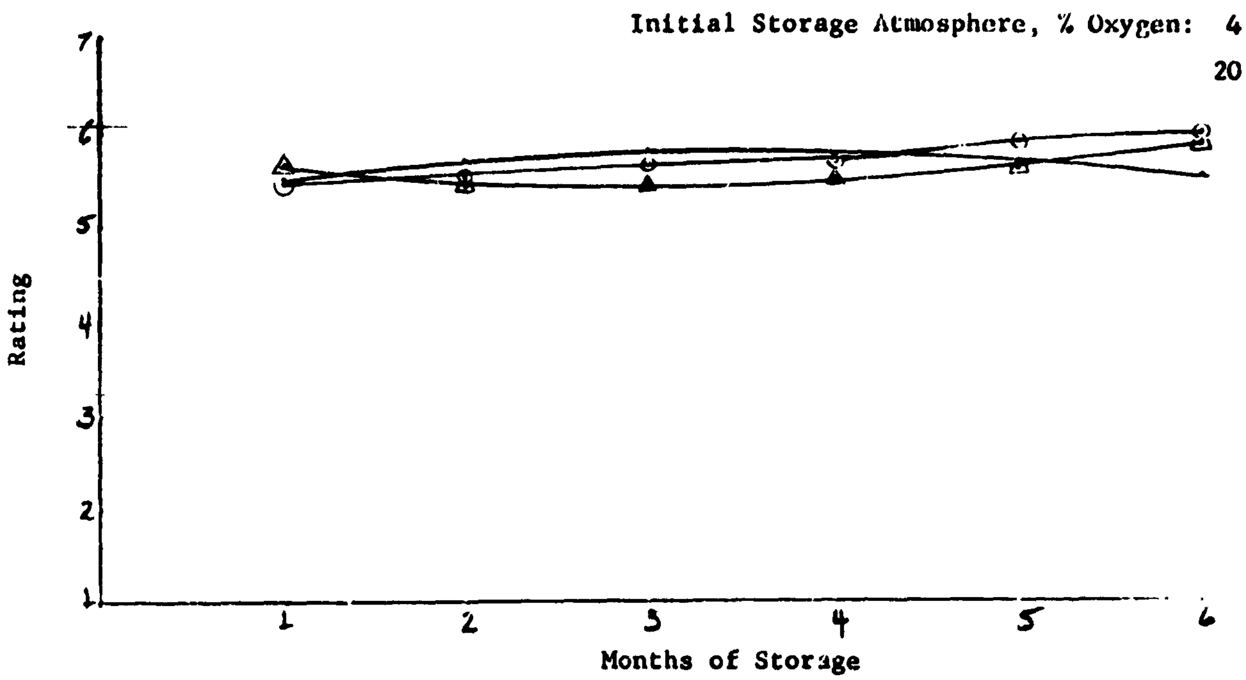


Correlation/Initial Storage Atmosphere - 2%: .12; 4%: .46; 20%: .43

Figure 5

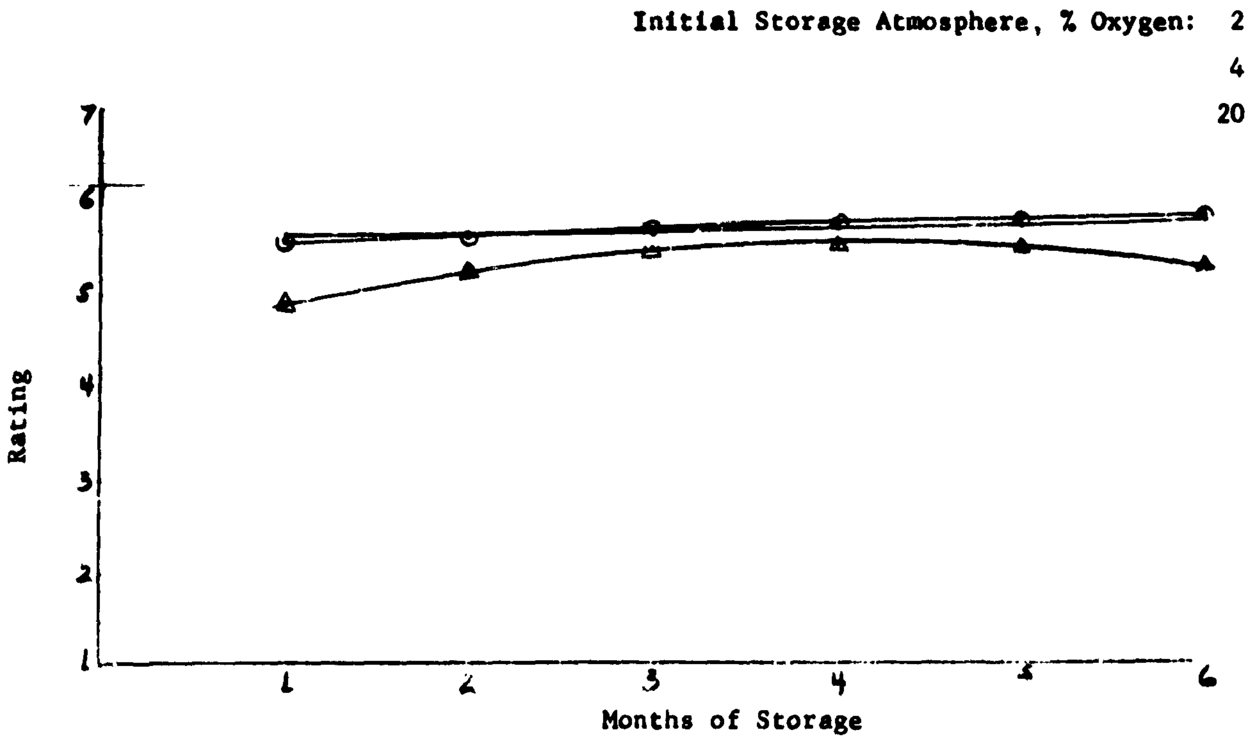
CARROT JUICINESS

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .30; 4%: .36; 20%: .25

B. 4% Moisture Samples

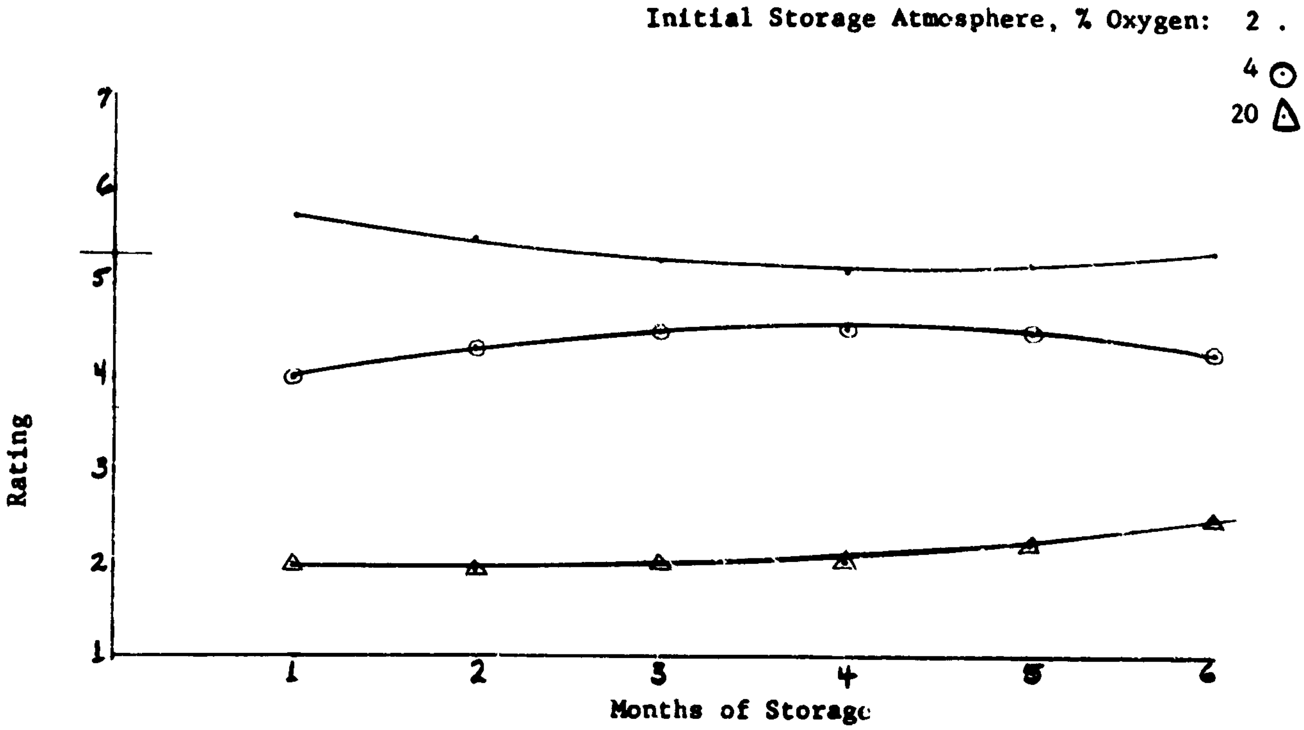


Correlation/Initial Storage Atmosphere - 2%: .03; 4%: .21; 20%: .28

Figure 6

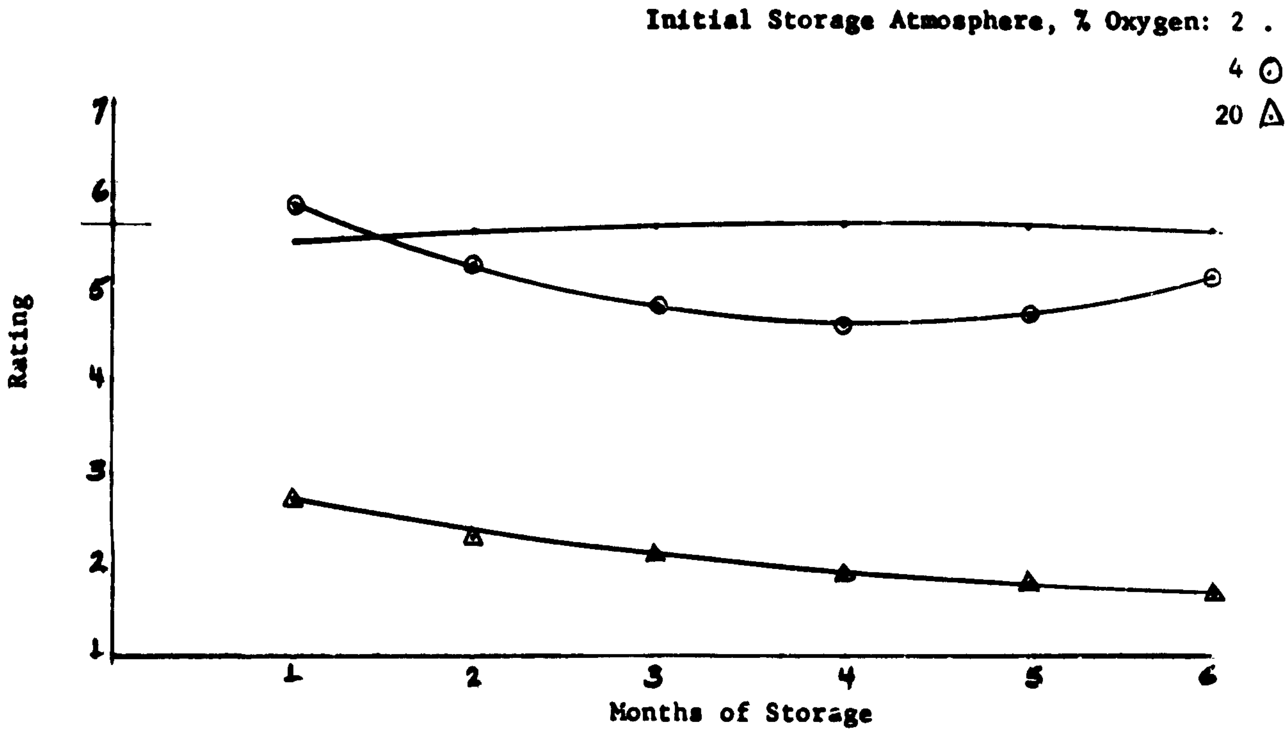
CARROT COLOR

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .60; 4%: .13; 20%: .42

B. 4% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .05; 4%: .73; 20%: .71

TABLE V

SUMMARY OF STATISTICAL ANALYSES

Test		Sensory Judgments						Rehydration Measurements	
Analysis of Variance	Source of Variation	Accept-ability	Aroma	Flavor	Texture	Juiciness	Color	Total Water Absorbed	Unbound Water
	Moisture, M				*				
	Oxygen, O	**	**	**	*	**	**		*
	Storage Time, T	*	*		*	**			
	MO					**		*	
	MT			*	**	**			
	OT					*			
Multiple Range	Initial Headspace Oxygen, Percent	*** 2/4/20	*** 2/4/20	*** 2/4/20		*** 4/20 ** 4&2/20	*** 2/4/20		

* p = .05
** p = .01
*** p = .005

TABLE VI

ANALYSIS OF VARIANCE: CARROT ACCEPTABILITY

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.07562	.07562	.99
Oxygen, O	2	23.48441	11.74220	153.14 **
Storage Time, T	5	1.39951	.27990	3.65 *
MO	2	.43532	.21766	2.84
MT	5	1.11292	.22258	2.90
OT	10	.53018	.05302	.69
MOT (Error)	10	.76676	.07668	
Total	35	27.80472		

TABLE VII

ANALYSIS OF VARIANCE: CARROT AROMA

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.08417	.08417	.53
Oxygen, O	2	21.38764	10.69382	67.88 **
Storage Time, T	5	4.42472	.88494	5.62 *
MO	2	.24791	.12396	.79
MT	5	1.54000	.30800	1.96
OT	10	1.15736	.11574	.73
MOT (Error)	10	1.57542	.15754	
Total	35	30.41722		

TABLE VIII

ANALYSIS OF VARIANCE: CARROT FLAVOR

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.00140	.00140	.01
Oxygen, O	2	22.61316	11.30658	94.90 **
Storage Time, T	5	.81633	.16326	1.37
MO	2	.09636	.04818	.40
MT	5	2.27496	.45499	3.82 *
OT	10	1.16705	.11671	.98
MOT (Error)	10	1.19135	.11914	
Total	35	28.16061		

TABLE IX

ANALYSIS OF VARIANCE: CARROT TEXTURE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.41174	.41174	5.13 *
Oxygen, O	2	1.04524	.52262	6.51 *
Storage Time, T	5	1.97785	.39557	4.92 *
MO	2	.13920	.06960	.87
MT	5	3.01951	.60390	7.52 **
OT	10	.85226	.08523	1.06
MOT (Error)	10	.80330	.08033	
Total	35	8.24910		

TABLE X

ANALYSIS OF VARIANCE: CARROT JUICINESS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.04694	.04694	3.56
Oxygen, O	2	.41542	.20771	15.77 **
Storage Time, T	5	1.57167	.31433	23.87 **
MO	2	.61500	.30750	23.35 **
MT	5	.48639	.09727	7.39 **
OT	10	.52541	.05254	3.99 *
MOT (Error)	10	.13417	.01317	
Total	35	3.79500		

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TABLE XI

ANALYSIS OF VARIANCE: CARROT COLOR

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.93444	.93444	4.19
Oxygen, O	2	74.00421	37.00210	165.82 **
Storage Time, T	5	.54139	.10827	.49
MO	2	.91086	.45543	2.04
MT	5	1.96139	.39227	1.76
OT	10	.40975	.04098	.18
MOT (Error)	10	2.23143	.22314	
Total	35	80.99347		

TABLE XII

ANALYSIS OF VARIANCE: WATER ABSORBED DURING RECONSTITUTION, PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.08410	.08410	1.04
Oxygen, O	2	.28121	.14061	1.73
Storage Time, T	5	.96839	.19368	2.39
MO	2	.83971	.41986	5.17 *
MT	5	.54367	.10873	1.34
OT	10	.85389	.08539	1.05
MOT (Error)	10	.81152	.08115	
Total	35	43.38249		

TABLE XIII

ANALYSIS OF VARIANCE: UNBOUND WATER, PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.25671	.25671	.71
Oxygen, O	2	4.04894	2.02447	5.57 *
Storage Time, T	5	4.97835	.99567	2.74
MO	2	2.39474	1.19737	3.30
MT	5	2.02516	.40503	1.12
OT	10	1.63823	.16382	.45
MOT (Error)	10	3.63169	.36317	
Total	35	18.97382		

TABLE XIV

CARROT ACCEPTABILITY, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
	2	4.775	4.650	4.625	4.325	4.425	4.925
2	4	4.225	3.100	4.100	3.825	3.650	3.950
	20	2.925	2.500	2.850	3.075	2.425	2.675
	2	4.475	4.875	4.625	4.775	3.575	4.275
4	4	4.375	4.450	3.750	4.125	3.700	3.725
	20	2.300	2.675	2.525	2.675	1.725	2.750

TABLE XV

CARROT AROMA, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	5.300	4.550	4.250	4.200	3.700	5.200
	4	4.800	2.700	3.650	4.200	2.800	3.750
	20	3.250	2.000	2.700	3.050	2.150	3.300
4	2	4.800	4.450	4.850	5.100	4.150	4.000
	4	4.500	4.000	3.500	4.000	3.900	3.800
	20	2.500	2.300	2.650	2.850	2.250	3.050

TABLE XVI

CARROT FLAVOR, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage					
		1	2	3	4	5	6
2	2	3.950	4.600	4.325	4.400	4.900	4.750
	4	4.300	2.900	4.100	3.850	3.750	3.650
	20	2.650	2.250	2.550	2.700	2.500	2.800
4	2	4.650	4.850	4.550	4.100	3.600	4.600
	4	4.500	4.650	3.400	3.950	3.200	3.650
	20	2.450	2.800	2.250	2.650	1.900	2.950

TABLE XVII

CARROT TEXTURE, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage					
		1	2	3	4	5	6
2	2	5.850	5.500	5.750	5.800	5.300	4.950
	4	5.600	5.400	5.850	5.300	6.250	5.100
	20	5.500	4.900	5.250	5.350	5.500	5.350
4	2	5.000	6.150	6.050	5.350	4.650	5.600
	4	5.200	6.300	5.650	5.050	5.100	4.900
	20	4.350	5.800	5.600	4.650	4.750	4.500

TABLE XVIII

CARROT JUICINESS, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	5.500	5.750	5.800	6.000	5.350	5.650
	4	5.500	5.450	6.150	5.500	5.750	6.200
	20	5.500	5.550	5.900	5.300	5.300	6.200
4	2	5.350	6.100	5.950	5.500	5.400	6.100
	4	5.500	5.900	5.650	5.550	6.000	5.800
	20	4.650	5.850	5.600	5.300	5.250	5.600

TABLE XIX

CARROT COLOR, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	5.700	5.550	5.400	4.900	5.400	5.300
	4	4.400	3.400	5.025	4.550	4.600	4.150
	20	2.100	1.750	2.375	1.800	2.400	2.500
4	2	5.400	5.900	5.600	5.400	5.800	5.600
	4	5.700	5.750	4.600	4.650	4.600	5.300
	20	2.700	2.550	1.900	2.250	1.500	1.900

TABLE XX

PRODUCT DESCRIPTION,

TERMINATION OF STORAGE

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Dehydrated		Rehydrated				
		Aroma	Color	Aroma	Flavor	Texture	Juiciness	Color
2	2	Carrot, Hay	Faded, Bleached (2)**	Faint Carrot	Carrot, Flat, Lacking Sweetness, Hay	Fairly Tender	Very Juicy, Slightly Soggy	Slight Bleached (2)* Orange Cast
	4	Carrot, Hay	Faded, Bleached (2)	Almost Odorless, Faint Carrot, Hay	Moderately Sweet Carrot, Moderate Hay	Moderately Tender	Fairly Juicy	Moderate, Bleached, Orange Cast, Translucent (
	20	Hay, Acid, Paint or Varnish	Bleached Light, White (5)	Faint Malic	Sweet, Caramel, Hay, Bitter	Moderately Tough	Fairly Juicy	Bleached, Pal Yellow Cast (
4	2	Acid Malic	Faded (1)	Carrot, Caramel	Sweet Carrot	Fairly Tender	Very Juicy, Slightly Soggy	Very Slightl Faded (1), Deep Orange, Faint Brown (
	4	Acid, Malic	Faded, Bleached, Yellow Cast (3)	Faint Carrot	Sweet Carrot, Caramel, Slight Hay	Moderately Tender	Very Juicy	Moderate Ble Yellow - Bro Cast, Translucent
	20	Acid, Malic	Bleached, Yellow-Brown Cast (6)	Carmelized, "Graham Cracker"	Very Sweet Carrot, Hay, Medicinal	Moderately Tough, Oily	Fairly Juicy	Bleached, Pa Yellow-Brown Cast (6)
2*	0	Odorless	Typical	Carrot Top	Carrot	Tender, Turgid	Fairly Juicy, Retains water well. No tendency to-	Typical

* Storage Temperature: -10°F

IV. SPINACH

There does not appear to be any published study relating storage environment of freeze-dehydrated spinach to stability

RESULTS

Oxygen Absorption

Table I shows the absorption of headspace oxygen by precooked, freeze-dehydrated spinach during storage. Variations in the amount of oxygen absorbed by spinach dried to the two residual moisture levels and stored under the various atmospheres were tested statistically. Differences in the amounts of oxygen absorbed at the two residual moisture levels were not significant. The rate of oxygen absorption appeared to be quite irregular. Under lower oxygen concentrations, rate of absorption decreased with storage time. Samples stored in 20% oxygen atmospheres exhibited a decrease in rate of absorption as storage progressed followed by an increased rate of absorption after the fourth month of storage.

Carbon Dioxide Production

Carbon dioxide production during storage of spinach is shown in Table II. In general, carbon dioxide production was a terminal reaction. However, onset of production appeared to be related to storage atmosphere and to residual moisture level. Carbon dioxide was detected in each of the various headspace atmospheres of the 4% residual moisture samples. In contrast, only the samples of product dried to the 2% residual moisture level and stored under 20% oxygen atmospheres evidenced terminal carbon dioxide production.

Rehydration Characteristics

Measurements of the extent of reconstitution and amount of water expressed under pressure are shown in Tables III and IV. The use of press technique as a measure of water holding capacity of leafy vegetables has not been reported. The validity and reliability of applying this technique as an adequate measure of deteriorative changes are questionable. Further, the use of extent of rehydration as a measure of the quality of relatively small pieces of spinach is doubtful; the possibility of entrapment of free water between the pieces resulting in incomplete drainage must certainly be considered. This measure may be more reliable in evaluating foods of more discreet particle size.

Quality Attributes

Figures 3 through 6 show the changes in quality attributes through the storage period. Generally, the samples processed to the 4% residual moisture level showed more extensive deterioration in acceptability, aroma, flavor, texture, and juiciness during the initial storage period and during the storage study. However, the 4% residual moisture sample stored in 20% oxygen atmospheres deteriorated most rapidly during the first month of storage and did not follow this trend in rate of degradation during storage. Again, changes in aroma and flavor paralleled those in acceptability. While changes in texture and juiciness were evident and of a more serious nature than those occurring in carrots, these changes were not as serious as those in structural properties of protein foods.

Statistical Analyses

The statistical analyses of sensory judgments and rehydration measurements are summarized in Table V. Tables VI through XI show the analysis of variance of sensory characteristics. Analyses of variance of rehydration measurements are shown in Tables XII and XIII. Tables XIV through XIX show the mean ratings of sensory characteristics during the study.

As indicated in Table V, sensory qualities of precooked, freeze-dehydrated spinach were generally affected by each of the variables under study. Deteriorative changes were implimented by increases in residual moisture content of the product, oxygen concentration of the headspace of the storage container, and length of storage at elevated temperature.

Moisture level appeared to regulate the rate and type of reaction. The 4% residual moisture samples showed much more extensive changes in all quality attributes except color at the initial evaluation. Similarly, the terminal effect of moisture on acceptability, aroma, flavor, and texture may be attributed to onset of reactions responsible for carbon dioxide production.

Color changes during storage were an obvious exception to this general pattern of degradation although there was an oxidative effect. According to Braverman's review of chlorophyll (1963), the disappearance of chlorophyll is associated with oxidation. This reaction did not appear to be operative in this experiment. However, such reactions are exceedingly complex and require chemical documentation. There are several factors which should be considered:

(1) Protochlorophyll may act as a hydrogen acceptor and undergo transformation to alpha chlorophyll. Each chlorophyll compound is known to be characterized by its own absorption spectrum (Biochemists' Handbook).

(2) A colorless phase is common to all chlorophyll containing plants. Apparently, a certain amount of iron is necessary in order to transform the colorless phase to green chlorophyll (Braverman, 1963).

(3) The enzyme, chlorophyllase, may not be inactivated during the

cooking operation and may continue to convert chlorophyll into chlorophyllin. This phenomenon appears to be seasonal. Chlorophyllase is practically inactive in the summer. However, in the spring, the enzyme will continue to convert chlorophyll to chlorophyllin although the vegetable is subjected to a temperature of approximately 170°F for a 20 minute period (Braverman, 1963). According to Acker (1962), there have been few systematic investigations relating enzyme activity and residual moisture content. There are indications that it may not be possible to establish a limiting relative humidity for certain enzymic reactions. The limiting effect of moisture reflects ability to facilitate diffusion of the enzyme and substrate. In the case of a fully precooked product, cell walls offer less resistance to contact of enzyme and substrate. Accordingly, the possibility of some enzymic activity exists. This activity might be associated with rehydration. The extreme viability of enzymes and bacteria in the dehydrated state has been noted in studies of gas production by certain rehydrated foods during tests conducted by Whirlpool Corporation, (Wheaton, et al, 1963). However, typical intensification of color on rehydration could also account for this.

(4) Green coloring matter was apparent in the rehydration water. Chlorophyllase detaches the phytol moiety from chlorophyll, causing dissolution of green coloring pigment in water. The removal of phytol by hydrolysis also yields water soluble methyl chlorophyllide (Braverman, 1963).

(5) The destruction of other, more labile pigments such as the carotenoids may account for the seeming improvement in color of spinach through storage.

(6) The action of even a very weak acid results in removal of magnesium from the chlorophyll molecule resulting in formation of pheophytin. In situ, chlorophyll is bound to lipoproteins in a manner which protects it from acid. Heating coagulates the proteins and exposes chlorophyll to the adverse action of acids. Factors of cooking and dehydration being equal, some acid formation is a possible factor in samples packaged under 20% oxygen atmosphere.

Physical measurements showed that the 4% residual moisture samples absorbed a significantly greater amount of water during reconstitution. This water was not immobilized and was easily expressed under pressure. Subjectively, this moisture created the impression of excessive sogginess and limpness.

The immobilization of water by tissue over the storage period was somewhat at variance with subjective judgments of structural characteristics although there was a similarity in trend among the various subjective and objective measures of structural properties. This variance indicates that use of this particular method of objective measurement as a precise tool in evaluating structural qualities of this type of vegetable is doubtful. However, the similarity in trend suggests that refinement in technique of sample preparation, redesign of press equipment, or change in method could improve the accuracy of measurement.

Both the subjective judgments and bound water measurements indicated that the effect of residual moisture content on immobilisation of water by the product varied considerably over the storage period.

Table XX details product characteristics at the termination of storage.

RECOMMENDATIONS

Adequate storage life for this commodity is dependent on dehydration to the 2% residual moisture level and virtual exclusion of atmospheric oxygen during packaging and storage.

TABLE I

ABSORPTION OF HEADSPACE OXYGEN, ML. PER GRAM

Residual Moisture, Percent	Initial Storage Atmosphere, Percent O_2	Months of Storage 1	2	3	4	5	6
2	2	0.30	0.30	0.54	0.64	0.64	0.64
	4	0.51	0.61	0.81	0.81	0.91	0.95
	20	--	1.02	1.66	1.52	3.56	2.81
4	2	0.00	0.28	0.49	0.63	0.46	0.56
	4	0.42	0.67	0.84	0.95	0.88	0.98
	20	0.91	1.44	1.72	1.86	2.10	2.88
Control	0	0	0	0	0	0	0

TABLE II

CARBON DIOXIDE IN HEADSPACE OF STORAGE CONTAINER, ML. PER GRAM

Residual Moisture, Percent	Initial Storage Atmosphere, Percent O_2	Months of Storage 1	2	3	4	5	6
2	2	0	0	0	0	0	0
	4	0	0	0	0	0	0
	20	0	0	0	0	0.27	0.1[illegible]
4	2	0	0	0.11	0	0	0.84
	4	0	0	0	0	0.28	0.14
	20	0	0	0.28	0.14	0.70	0.32
Control	0	0	0	0	0	0	0

TABLE III

WATER ABSORBED DURING RECONSTITUTION,

PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage					
		1	2	3	4	5	6
2	2	1320	1118	1049	1141	1021	1110
	4	1202	1167	1095	1088	1071	1157
	20	1090	1035	966	1119	1033	1112
4	2	1168	1263	1219	1186	1262	1065
	4	1191	1233	1236	1372	1184	1359
	20	1047	1562	1180	1266	1200	1194

TABLE IV

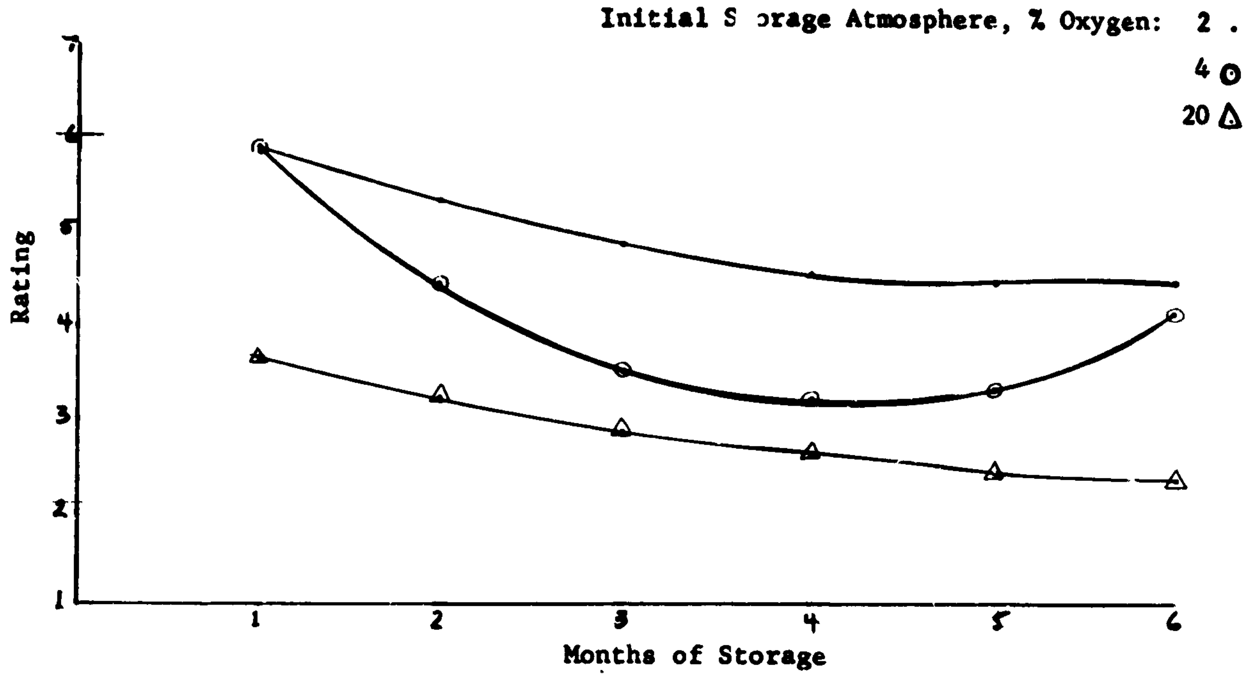
UNBOUND WATER,

PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage					
		1	2	3	4	5	6
2	2	1128	905	837	942	845	904
	4	950	899	874	893	885	940
	20	886	804	754	917	830	919
4	2	943	1032	1020	982	1051	943
	4	1005	1010	1045	1131	974	1166
	20	850	1336	930	992	1021	976

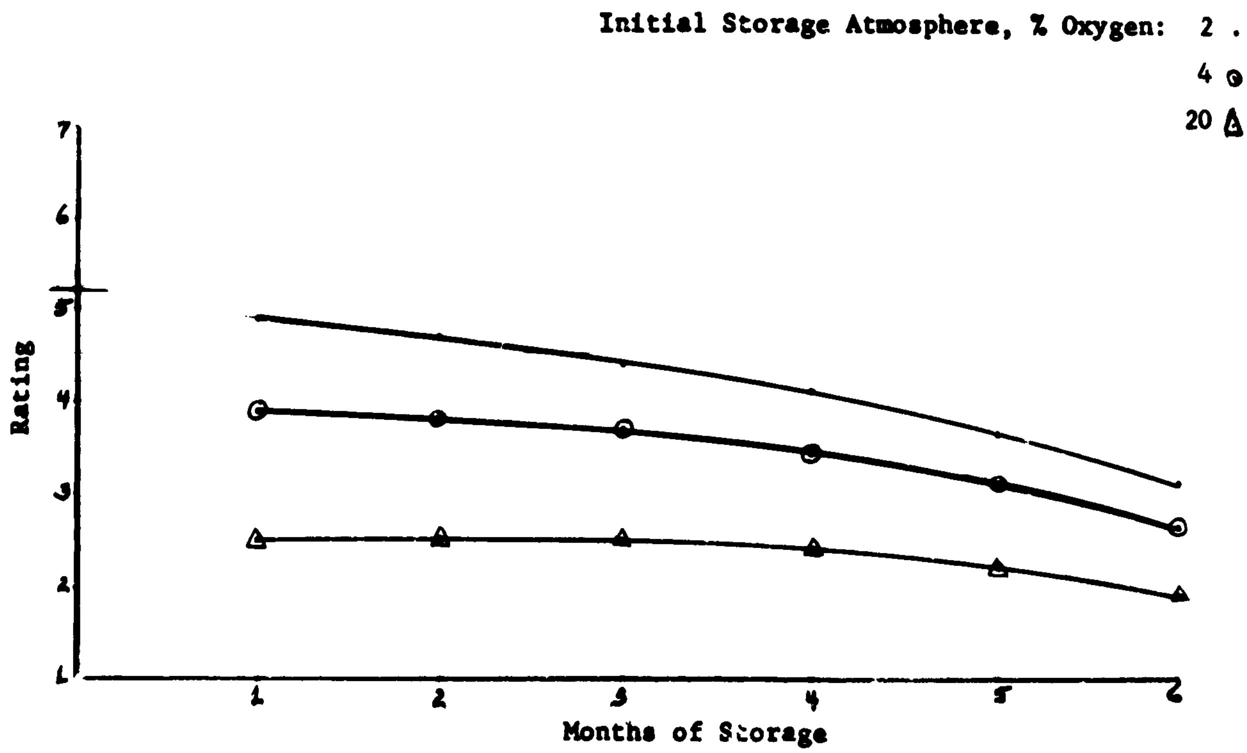
SPINACH ACCEPTABILITY

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .63; 4%: .66; 20%: .54

B. 4% Moisture Samples



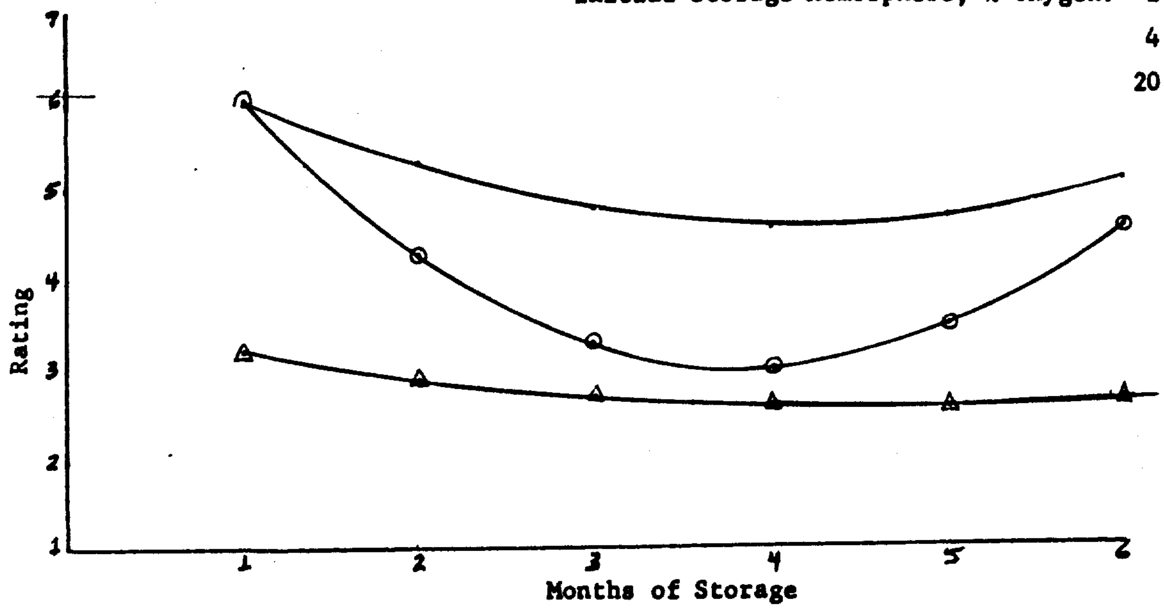
Correlation/Initial Storage Atmosphere - 2%: .53; 4%: .72; 20%: .67

Figure 2

SPINACH AROMA

A. 2% Moisture Samples

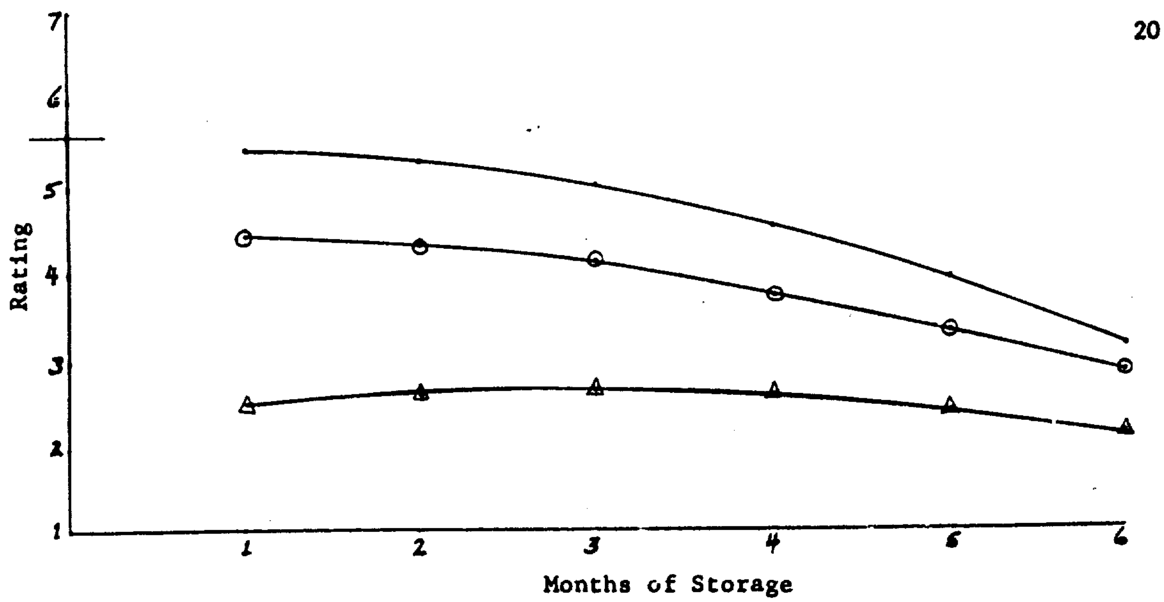
Initial Storage Atmosphere, % Oxygen: 2 .
4 ⊙
20 Δ



Correlation/Initial Storage Atmosphere - 2%: .43; 4%: .66; 20%: .25

B. 4% Moisture Samples

Initial Storage Atmosphere, % Oxygen: 2 .
4 ⊙
20 Δ

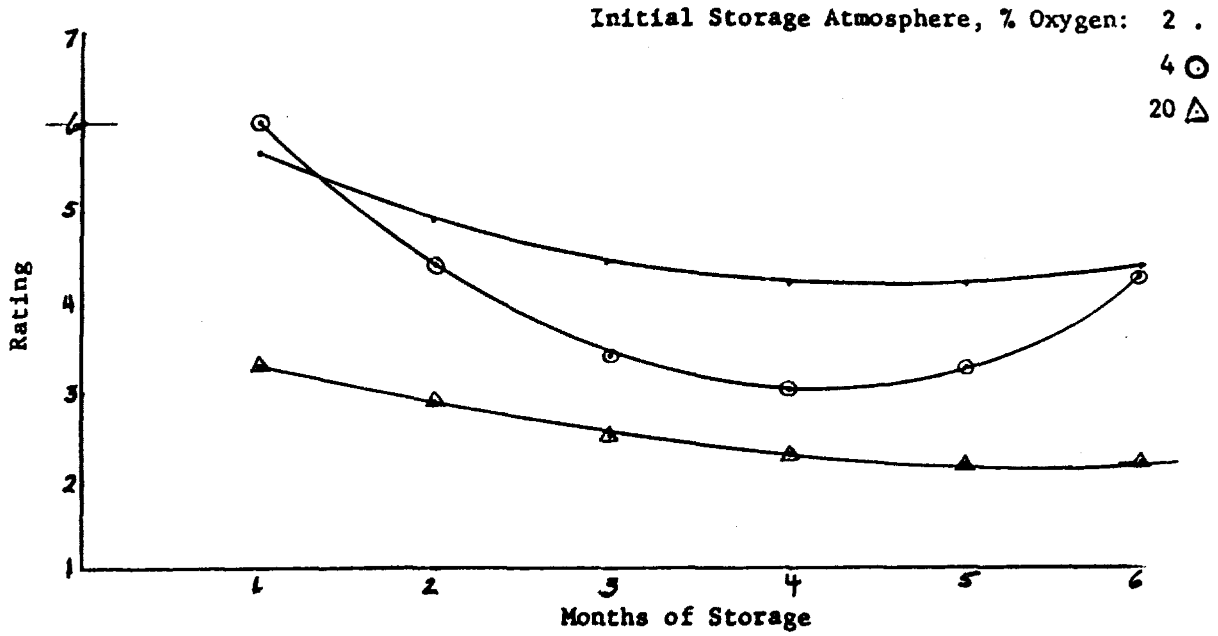


Correlation/Initial Storage Atmosphere - 2%: .85; 4%: .96; 20% .35

Figure 3

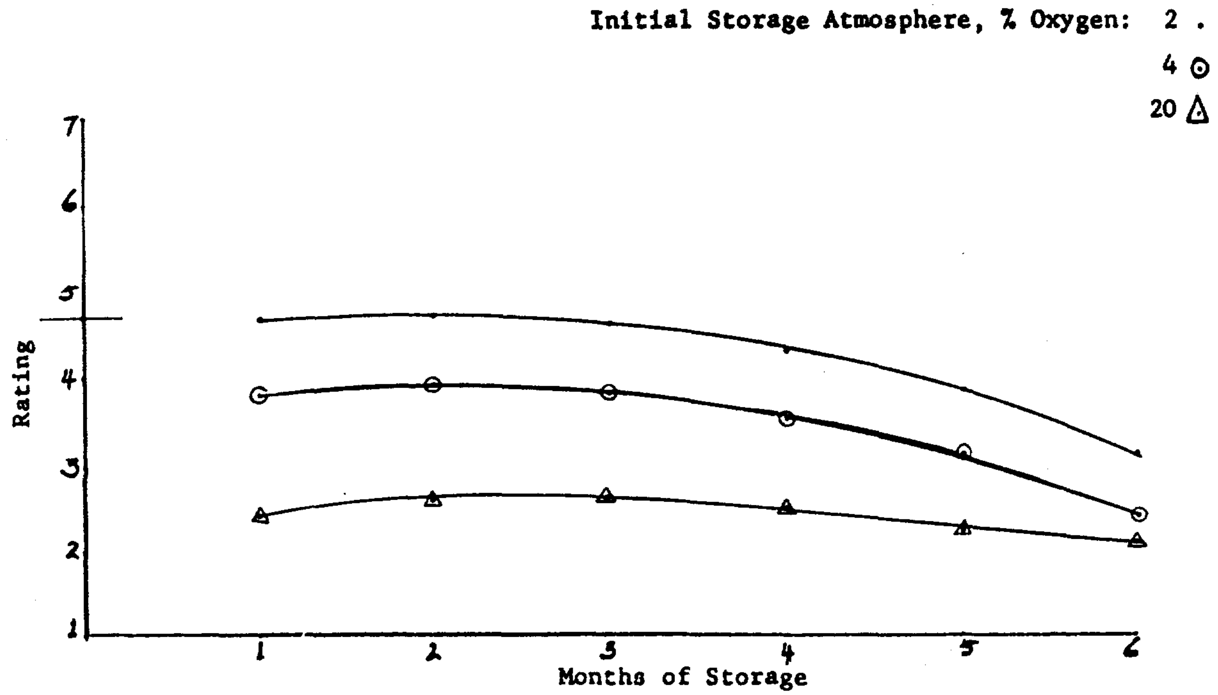
SPINACH FLAVOR

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .62; 4%: .58; 20%: .59

B. 4% Moisture Samples

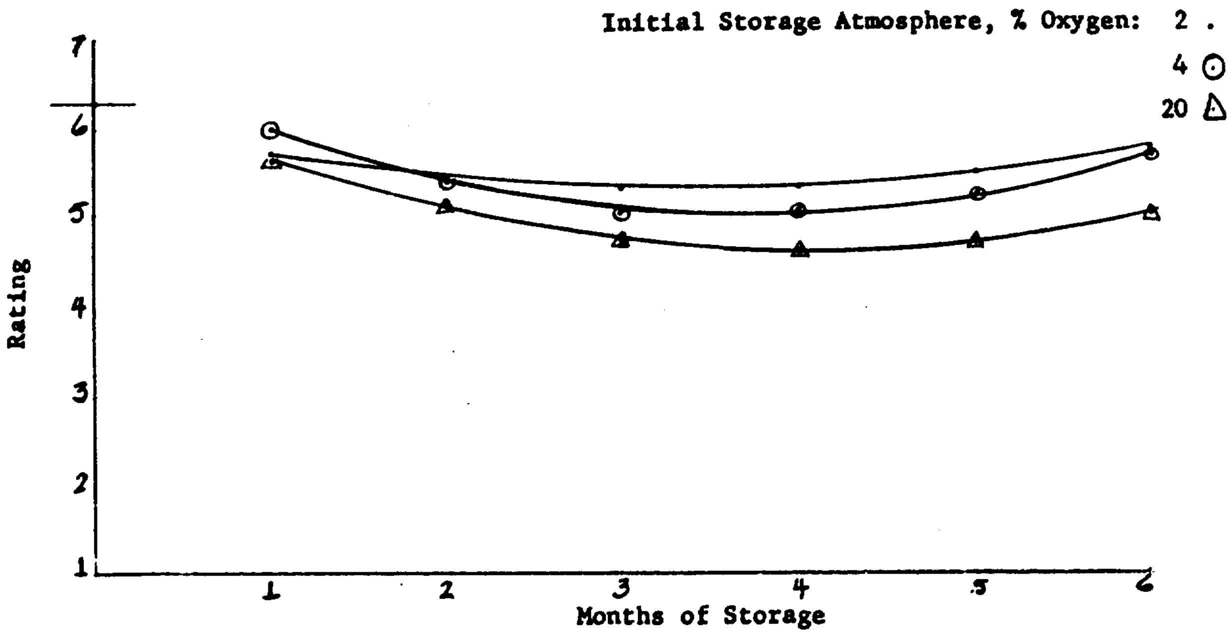


Correlation/Initial Storage Atmosphere - 2%: .51; 4%: .68; 20% .50

Figure 4

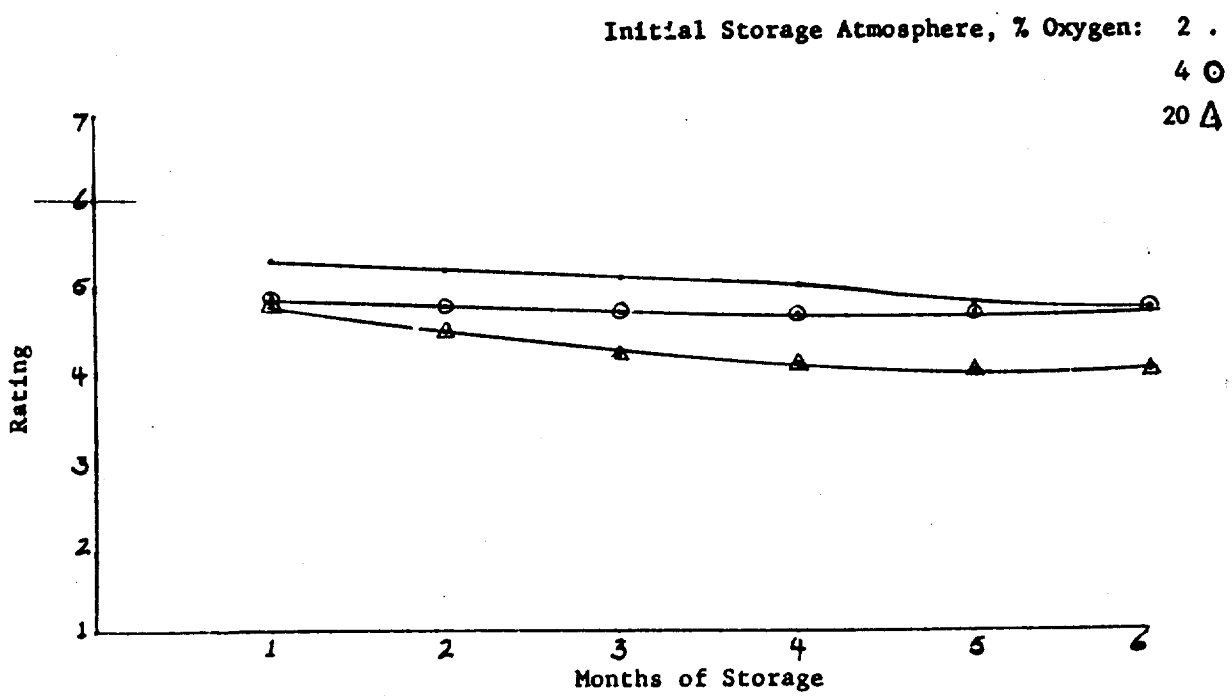
SPINACH TEXTURE

A. 2% Moisture Samples



Correlation/Initial Storage Atmosphere - 2%: .61; 4%: .73; 20%: .85

B. 4% Moisture Samples



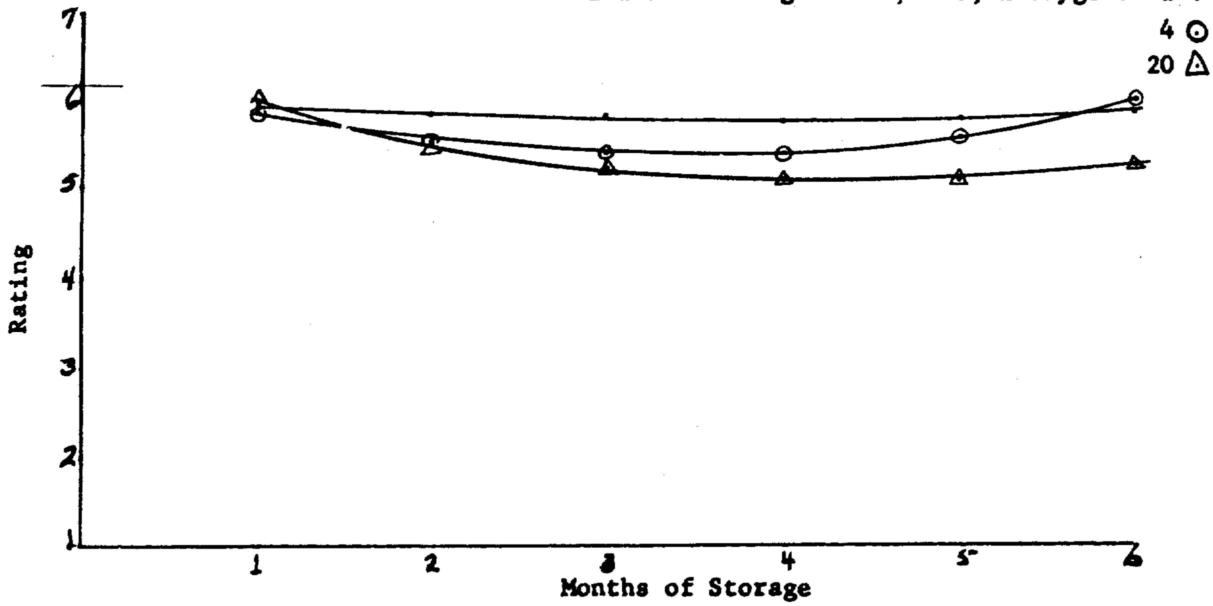
Correlation/Initial Storage Atmosphere - 2%: .19; 4%: .40; 20%: .60

Figure 5

SPINACH JUICINESS

A. 2% Moisture Samples

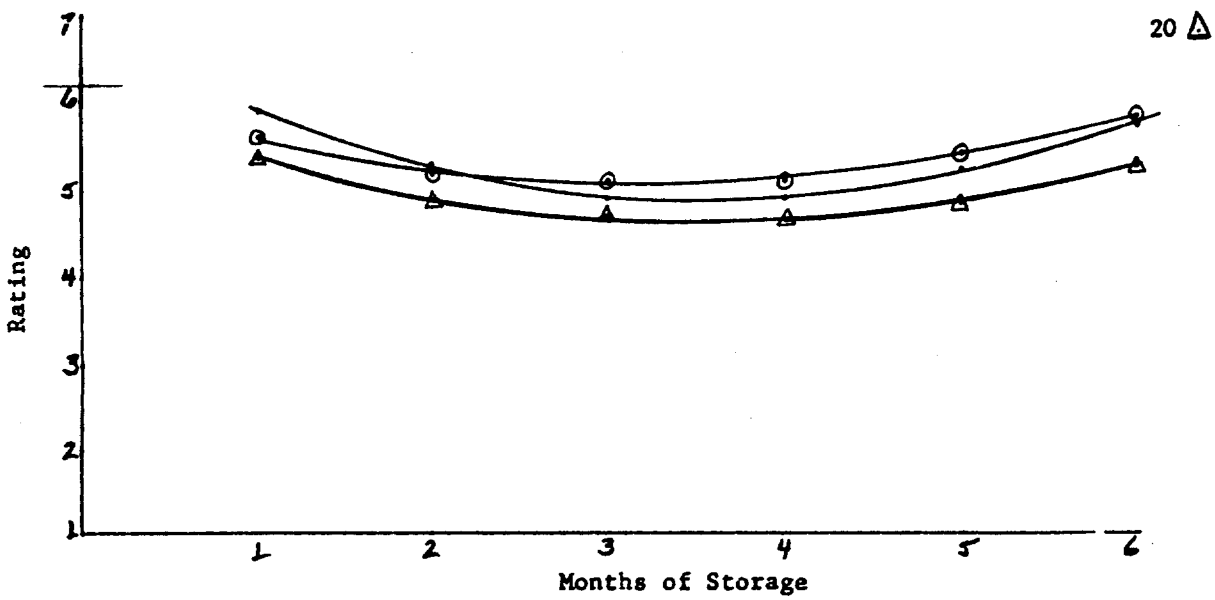
Initial Storage Atmosphere, % Oxygen: 2 .
4 ⊙
20 △



Correlation/Initial Storage Atmosphere - 2%: .20; 4%: .57; 20%: .85

B. 4% Moisture Samples

Initial Storage Atmosphere, % Oxygen: 2 .
4 ⊙
20 △



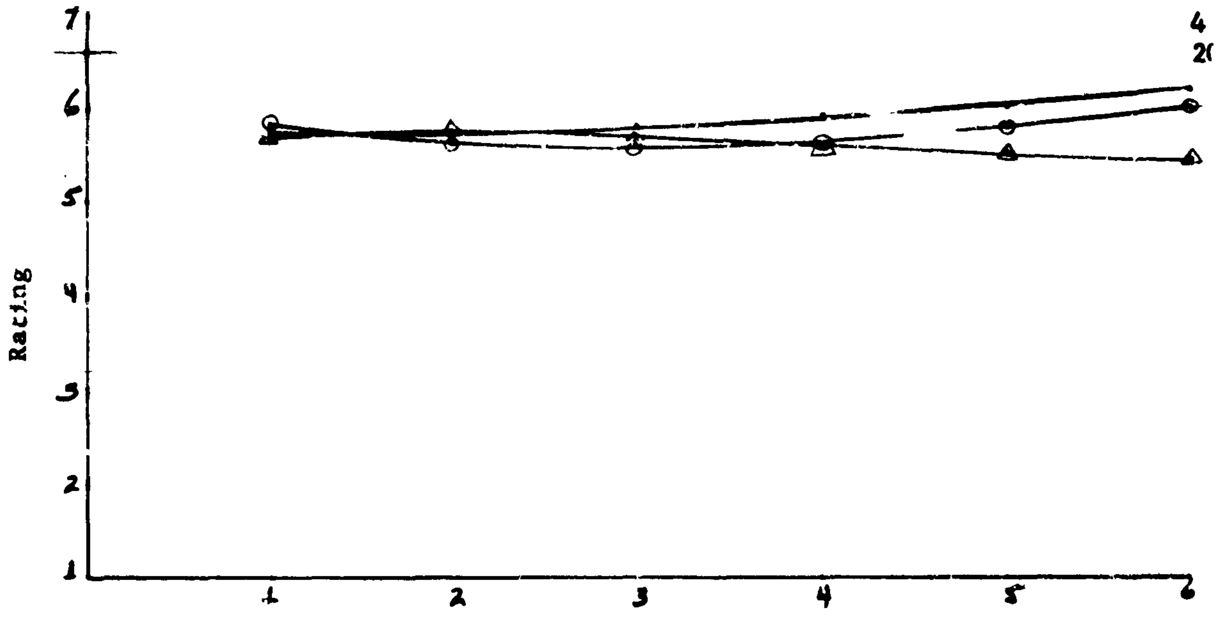
Correlation/Initial Storage Atmosphere - 2%: .62; 4%: .45; 20%: .62

Figure 6

SPINACH COLOR

A. 2% Moisture Samples

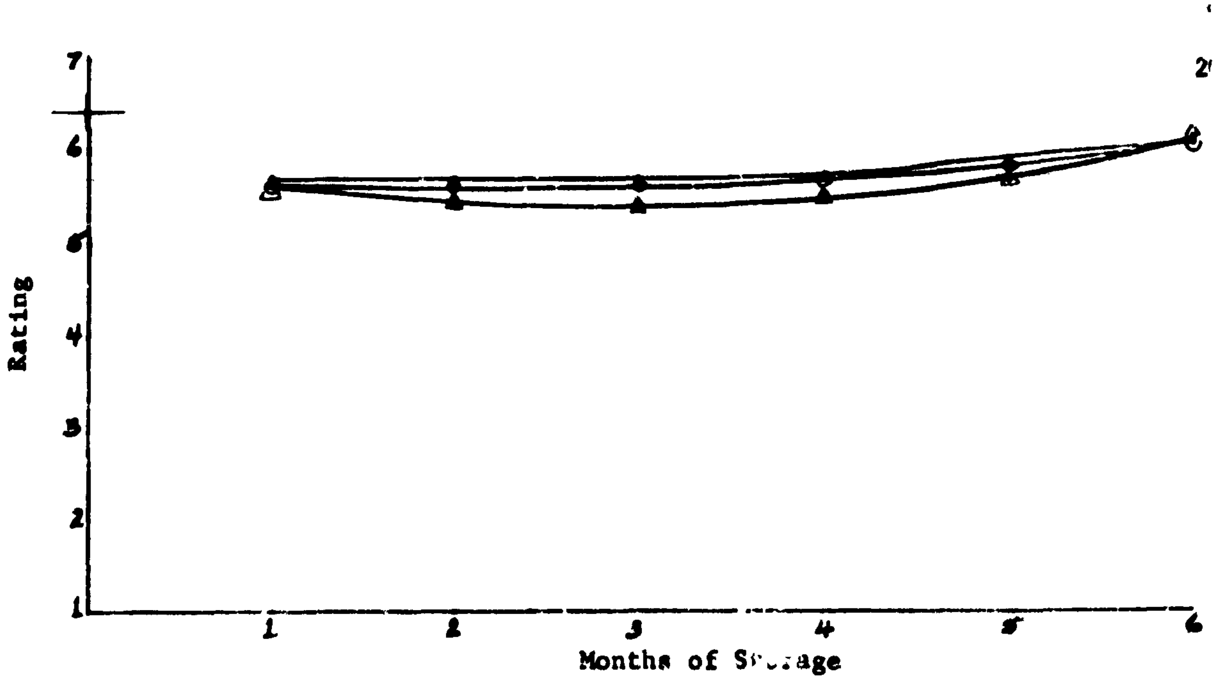
Initial Storage Atmosphere, % Oxygen: 2



Correlation/Initial Storage Atmosphere - 2%: .80; 4%: .37; 20%: .34

B. 4% Moisture Samples

Initial Storage Atmosphere, % Oxygen:



Correlation/Initial Storage Atmosphere - 2%: .30; 4%: .29; 20%: .33

TABLE V

SUMMARY OF STATISTICAL ANALYSES

Test		Sensory Judgments						Rehydration Measurements	
Analysis of Variance	Source of Variation	Accept-ability	Aroma	Flavor	Texture	Juiciness	Color	Total Water Absorbed	Unbound Water
	Moisture, M	**	*	*	**	**		**	**
	Oxygen, O	**	**	**	**	*	*		
	Storage Time, T	**	**	**	**	*	**		
	MO								
	MT	*	*	**	*		*		
	OT								
Multiple Range	Initial Headspace Oxygen, Percent	*** 2/4/20	*** 2/4/20	*** 2/4/20	*** 2&4/20	** 2/20			

* p = .05

** p = .01

*** p = .005

TABLE VI

ANALYSIS OF VARIANCE: SPINACH ACCEPTABILITY

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	3.42250	3.42250	18.50 *
Oxygen, O	2	22.99233	11.49616	62.15 *
Storage Time, T	5	11.55826	2.31165	12.50 *
MO	2	.08072	.04036	.22
MT	5	4.43584	.88717	4.80 *
OT	10	1.35434	.13543	.73
MOT (Error)	10	1.84969	.18497	
Total	35	45.69368		

TABLE VII

ANALYSIS OF VARIANCE: SPINACH AROMA

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	1.44000	1.44000	7.39 *
Oxygen, O	2	28.81931	14.40966	73.94 *
Storage Time, T	5	10.76389	2.15277	11.04 *
MO	2	.07125	.03562	.18
MT	5	5.32500	1.06500	5.46 *
OT	10	3.07069	.30707	1.58
MOT (Error)	10	1.94875	.19488	
Total	35	51.43889		

TABLE VIII

ANALYSIS OF VARIANCE: SPINACH FLAVOR

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	1.64695	1.64695	9.18 *
Oxygen, O	2	23.44764	11.72382	65.32 **
Storage Time, T	5	11.77889	2.35577	13.12 **
MO	2	.30430	.15215	.85
MT	5	5.92389	1.18477	6.60 **
OT	10	2.06653	.20665	1.15
MOT (Error)	10	1.79486	.17949	
Total	35	46.96306		

TABLE IX

ANALYSIS OF VARIANCE: SPINACH TEXTURE

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	3.39174	3.39174	58.58 **
Oxygen, O	2	2.63181	1.31590	22.73 **
Storage Time, T	5	2.08701	.41740	7.21 **
MO	2	.05180	.02590	.45
MT	5	1.34368	.26873	4.64 *
OT	10	1.03736	.10374	1.79
MOT (Error)	10	.57903	.05790	
Total	35	11.12243		

TABLE X

ANALYSIS OF VARIANCE: SPINACH JUICINESS

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	1.48028	1.48028	16.77 **
Oxygen, O	2	1.21722	.60861	6.89 *
Storage Time, T	5	2.29556	.45911	5.20 *
MO	2	.10722	.05361	.61
MT	5	.47472	.09494	1.08
OT	10	.65611	.06561	.74
MOT (Error)	10	.88278	.08828	
Total	35	7.11389		

TABLE XI

ANALYSIS OF VARIANCE: SPINACH COLOR

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	.00250	.00250	.75
Oxygen, O	2	.31681	.15841	4.75 *
Storage Time, T	5	1.57639	.31527	9.44 **
MO	2	.03791	.01896	.57
MT	5	.91083	.18217	5.46 *
OT	10	.18819	.01882	.56
MOT (Error)	10	.33376	.03338	
Total	35	3.36639		

TABLE XII

ANALYSIS OF VARIANCE: WATER ABSORBED DURING RECONSTITUTION, PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	14.60513	14.60513	17.94 **
Oxygen, O	2	1.40281	.70141	.86
Storage Time, T	5	4.81955	.96391	1.18
MO	2	1.99551	.99776	1.23
MT	5	9.02559	1.80512	2.22
OT	10	7.67476	.76748	.94
MOT (Error)	10	8.14092	.81409	
Total	35	47.66427		

TABLE XIII

ANALYSIS OF VARIANCE: UNBOUND WATER, PERCENT DRY WEIGHT ADJUSTED FOR RESIDUAL MOISTURE CONTENT OF THE LOT

Source of Variation	Degrees of Freedom	Sum of Squares	Mean Square	Calculated F Ratio
Moisture, M	1	14.37673	14.37673	17.62 **
Oxygen, O	2	1.20605	.60303	.74
Storage Time, T	5	2.93525	.58705	.72
MO	2	1.54681	.77341	.95
MT	5	8.07002	1.61400	1.98
OT	10	7.08542	.70854	.87
MOT (Error)	10	6.15839	.81584	
TOTAL	35	41.37867		

TABLE XIV

SPINACH ACCEPTABILITY, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
	2	6.275	4.675	4.800	4.725	4.950	4.075
2	4	6.525	3.550	3.125	3.775	4.100	3.550
	20	3.950	2.925	2.275	3.200	2.750	2.050
	2	4.925	5.050	3.825	5.100	2.900	3.375
4	4	3.975	3.975	3.250	3.925	3.000	2.675
	20	2.525	2.525	2.500	2.700	1.950	2.000

TABLE XV

SPINACH AROMA, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	6.550	4.700	4.300	5.050	5.500	4.600
	4	6.750	3.450	2.750	3.700	4.400	4.000
	20	3.450	2.850	2.200	3.350	2.650	2.550
4	2	5.550	5.350	4.600	5.200	3.600	3.250
	4	4.600	4.150	4.050	3.900	3.450	2.800
	20	2.600	2.550	2.550	3.050	2.100	2.250

TABLE XVI

SPINACH FLAVOR, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	6.100	4.250	4.400	4.650	4.450	4.150
	4	6.800	3.400	2.750	3.700	4.500	3.550
	20	3.550	2.650	2.150	2.850	2.450	2.050
4	2	4.800	4.850	4.000	5.400	3.150	3.300
	4	3.900	3.950	3.300	4.200	2.950	2.450
	20	2.550	2.600	2.350	3.000	2.000	1.950

TABLE XVII

SPINACH TEXTURE, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	5.800	5.300	5.600	5.300	5.550	5.800
	4	6.200	5.200	4.900	5.200	5.550	5.550
	20	5.600	5.150	5.000	4.400	4.700	5.150
4	2	5.500	5.300	4.300	5.700	5.000	4.500
	4	5.100	4.650	4.250	5.200	4.900	4.600
	20	4.900	4.300	4.350	4.450	3.700	4.200

TABLE XVIII

SPINACH JUICINESS, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Months of Storage 1	2	3	4	5	6
2	2	6.100	5.700	6.150	5.700	5.700	6.000
	4	6.100	5.200	5.650	5.500	5.600	6.000
	20	5.900	5.700	5.250	5.200	4.950	5.450
4	2	6.050	5.250	4.600	5.500	5.050	5.700
	4	5.850	5.050	4.750	5.450	5.750	5.600
	20	5.450	4.700	5.100	4.600	4.700	5.400

TABLE XIX

SPINACH COLOR, MEAN VALUE

FOR THE STUDY

Residual Moisture, Percent	Initial Headspace Oxygen Percent	Months of Storage 1	2	3	4	5	6
2	2	5.850	5.600	5.800	6.000	6.100	6.200
	4	6.000	5.500	5.400	5.850	6.100	5.900
	20	5.800	5.700	5.500	5.600	5.800	5.300
4	2	5.900	5.350	5.900	6.000	5.650	6.200
	4	5.900	5.050	5.800	6.000	5.750	6.100
	20	5.900	4.850	5.800	5.800	5.550	6.200

TABLE XX

PRODUCT DESCRIPTION,

TERMINATION OF STORAGE

Residual Moisture, Percent	Initial Headspace Oxygen, Percent	Dehydrated		Rehydrated				
		Aroma	Color	Aroma	Flavor	Texture	Juiciness	Color
2	2	Spinach, Slight Hay	Typical	Faint Spinach	Typical	Fairly Tender	Fairly Juicy	Green, Light, Bright
	4	Sharp Spinach	Typical	Spinach, Slight Varnish	Strong Spinach, Moderate Bitter	Moderately Tough, Mealy	Soggy	Moderately Dark Green
	20	Tea, Faint Spinach	Very Slight Gray Cast	Tea	Bitter Scorched, Hay, Tea	Very Tough, Mealy	Soggy	Green; Very Slight Yellow Cast
4	2	Spinach, Moderate Hay	Typical	Strong Spinach	Strong Spinach	Tough, Mealy	Soggy	Green Light, Bright
	4	Sharp Spinach, Tea	Typical	Spinach, Slight Tea	Strong Bitter, Tea	Tough, Mealy	Soggy	Moderately Dark Green
	20	Strong Tea	Very Slight Yellow Cast	Strong Tea	Scorched, Bitter, Tea	Very Tough, Mealy	Soggy	Moderately Dark Green
2*	0	Odorless	Typical	Typical	Typical	Tender	Juicy, Turgid	Green

* Storage Temperature: -10°F

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APPENDIX

Panel Selection

Judgments of aroma, flavor, texture, juiciness, and color are necessarily subjective. However, adherence to certain recognized procedures can assure accurate and reliable evaluations (Boggs and Hanson, 1949).

As a preliminary step, personnel were contacted to ascertain willingness to participate in such a program if selected. Motivation was therefore a basic consideration. One hundred and three of 112 individuals contacted responded affirmatively.

From this group, fifty candidates were selected for acuity tests using interview screening technique. Selection criteria included availability from the standpoint of both general health and frequency of travel, the extent of food prejudice, and the ability to communicate effectively and spontaneously.

Tests were then conducted to select those individuals most capable of discerning differences in food qualities. Originally, it was intended that a two-phase acuity screening technique be employed. The first phase was to establish sensitivity to the four basic tests: sour, bitter, sweet, and salty. And the second phase was concerned with sensitivity to differences in the complex foods under study in this investigation.

Primary taste tests were conducted using chemically pure solutions of sodium chloride, lactic acid, caffeine, and sucrose prepared according to the procedures detailed by Krum (1955). The twenty-four individuals who found the two blank series flavorless and characterized the four test series appropriately within a range of $\pm$ 1 standard deviation of the mean were selected for further screening.

The second series of tests were conducted using commercially processed pre-cooked, freeze-dehydrated beef cubes, diced breast of chicken, diced carrots, and leaf spinach. These products were representative of the best quality available commercially, since variability of scores is greater on low than on high quality material. Representative portions of these commodities were subjected to accelerated storage conditions to induce deterioration. Meat and poultry products were exposed to atmospheric oxygen in an incubator operating at 113°F; vegetables were exposed to atmospheric oxygen and light to promote rapid color changes as well. Withdrawal of product from accelerated storage at intervals produced a series of graded difficulty. Thus a realistic test situation requiring discrimination and judgment similar to those anticipated in the actual study was used.

This second series of tests also served a number of other purposes:

1. To familiarize candidates with characteristics of freeze-dehydrated foods which in some cases are not closely aligned with those of freshly prepared fresh, frozen, or canned products customarily consumed.

2. To acquaint candidates with the specific characteristics which might evolve during the actual study, since it is difficult to detect off-odors or flavors where no standard exists for comparison.

3. To acquaint candidates with specified evaluation procedures.

4. To provide for adaptation to the testing of foods in an atypical manner; i.e., without the usual seasonings, butter, sauces, or gravies.

5. To familiarize the candidate with the system and technique of scoring in order to reduce the effect of this learning experience on initial tests in the actual study. The scoring form is shown in Attachment I.

Product preparation and service were essentially the same as those outlined in Procedures: Sensory Evaluations. Products held under nitrogen in the shipping containers and stored at -10°F were used as the warm-up samples and as identified and blind controls in all cases.

The secondary screening test data did not permit selection of an adequate number of taste panelists. The flavor of some food products is due to a complex mixture of odor, tastes, and mouth sensations. Thus the predominate flavors of foods in the study did not appear to be readily characterized by the primary tastes.

In view of this, additional members of the original group of fifty candidates, i.e., those not selected from analyses of primary taste test data, were also screened for sensitivity to complex food flavor differences. The total number of candidates tested for acuity to differences in a given commodity varied from 40 to 45, depending on the commodity.

Only those product evaluation series in which the unknown or test samples were correctly judged in predetermined relationship to the identified reference sample and in which little or no difference was indicated between identical control samples were subjected to statistical analyses. The regression line and control limits were calculated for each commodity. Candidates with scores falling within $\pm$ 1.5s were selected as panelists for the vegetables. The regression line $\pm$ 2s was used to select panelists for beef and chicken.

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[redacted] ______________________

DATE ______________

DIFFERENCE	SAMPLE J	SAMPLE F	SAMPLE H	SAMPLE
None	0	0	0	
	0.5	0.5	0.5	0.5
Very Slight	1	1	1	
	1.5	1.5	1.5	1.5
Slight	2	2	2	
	2.5	2.5	2.5	2.5
Moderate	3	3	3	
	3.5	3.5	3.5	3.5
Large	4	4	4	
	4.5	4.5	4.5	4.5
Extremely Large	5	5	5	
The Quality of the Test Sample is:				
Inferior to G				
Equal to G				
Superior to G				
Comments:				
Differences are Based on:				
1. Aroma				
2. Flavor				
3. Texture				
4. Juiciness				
5. Color(Vegetables)				

The Quality of Sample G is:
(Circle One)

Excellent
Good
Fair

Standard Sample (G)

Comments:

Unclassified
Security Classification

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1 ORIGINATING ACTIVITY *(Corporate author)*
Whirlpool Corporation, St. Joseph, Michigan

2a REPORT SECURITY CLASSIFICATION
Unclassified

2b GROUP

3 REPORT TITLE
EFFECT OF EXPOSURE TO OXYGEN ON CHANGES IN MEATS AND VEGETABLES DURING STORAGE

4 DESCRIPTIVE NOTES *(Type of report and inclusive dates)*
Final 24 June 1963 - 7 January 1965

5 AUTHOR(S) *(Last name, first name, initial)*
Roth, N., Wheaton, R. and Cope, P.

6 REPORT DATE	7a TOTAL NO OF PAGES	7b NO OF REFS
October 1965	126	2

8a CONTRACT OR GRANT NO.
DA 19-129-AMC-131(N)

b PROJECT NO
1K643303D548

c

d

9a ORIGINATOR'S REPORT NUMBER(S)

9b OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*
FD-31

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11 SUPPLEMENTARY NOTES

12 SPONSORING MILITARY ACTIVITY
Animal Products Branch, Food Division,
U. S. Army Natick Laboratories,
Natick, Mass. 01762

13 ABSTRACT

Reported are the procedures and results of a six-months' storage stability study conducted with precooked beef, chicken, carrots and spinach which had been freeze-dried to 2 and 4% residual moisture levels and stored under 2, 4, and 20% oxygen atmosphere at 100°F. Exposure to oxygen was the primary cause of product deterioration. The effect of residual moisture level and length of storage on quality attributes was product dependent.

DD FORM 1 JAN 64 1473

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
Storage stability	8		7			
Beef	9		7,4		1,2	
Chicken	9		7,4		1,2	
Carrots	9		7,4		1,2	
Spinach	9		7,4		1,2	
Precooked	0		0		0	
Freeze-dried	0		0		0	
Packaged			0			
Oxygen			6			
Moisture			6			
Packaging	8		4			
Oxidation					8	
Deterioration					8	
Nitrogen	5					

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